CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

KUHAN S/O PATHMATHEVAN

ABSTRACT

This is a Final Year Project entitled "Flow Dynamics of Natural Gas in a Metering Station for Natural Gas Vehicles".

The main objective for this project is to derive an equation that represents the relationship between pressure drop and energy loss in a metering station for natural gas vehicles. The system was divided into two sections. The first section is the pipeline which is from the source/reservoir till the end of pipe. The condition of flow in a pipe was applied when deriving the equation. The equation was tested against the data that was taken from a PETRONAS natural gas metering station. The second section is the receiver tank which is a closed tank. Thermodynamic relations were used to derive a relationship between the pressure drop and energy loss in the system. The equation was also tested against the same data.

This report will highlight the steps in deriving the equations for the respective sections. The graphical interpretation of the results has been included in this report to gain a better understanding of the relationship. The steps in creating the program to calculate the energy loss in the pipeline has also been included. This project is part of a study on how to improve the efficiency of natural gas metering stations.

ACKNOWLEDGEMENT

It has been a great pleasure to be able to complete the final year project which is a partial fulfillment of the requirements for the Bachelor of Engineering (Hons). First and foremost, I would like to extend my most grateful appreciation to my supervisor, Prof. Dr. V.R. Radhakrishnan for his valuable time and effort to guide and assist me in my progress of the final year project. He has given advices on the project which have enhanced my knowledge and skills towards completing this final year project.

I would like to express my sincere gratitude to Ms. Azizah, who has offered me her assistance in providing information that has helped in completing this project. Last but no least, I would like to extend my heartfelt appreciation to all the contributors whom have directly and indirectly played a role to the success of this final year project

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

The Chemical Engineering Final Year Project (ECB 5034) is a four credit hour course which involves research, modeling and experimental works. This project is entitled 'Flow Dynamics of Natural Gas in a Metering Station for Natural Gas Vehicles'. The supervisor of the project is Prof. Dr. V.R. Radhakrishan.

1.1 BACKGROUND OF STUDY

This project consists of the development of a model to calculate the energy loss occurring during the transfer of natural gas from the reservoir to the receiver. This is a subset of a larger project which is being conducted to increase the efficiency of metering station for natural gas vehicles.

There is a high pressure drop during the transfer of natural gas to the receiver which in this case is the car tank. The loss in pressure can be translated to energy loss in the system. Several equations to calculate the energy loss in different parts of the system was developed. These equations where developed based on the several criteria which will be discussed in the literature review section. All the data used to verify the equations where obtained from previous research. This study was only limited to the energy loss due to the pressure drop in the system.

1.2 PROBLEM STATEMENT

Natural gas is a vital component of the world's energy supply. It is one of the cleanest, safest, and most useful of all energy sources. Natural gas has long been considered an alternative fuel for the transportation sector. Natural gas vehicles as they exist today are best suited for large fleets of vehicles that drive many miles a day. With the demand increasing a lot of petrol stations are beginning to offer natural gas for vehicles.

One of the main problems being faced by these metering stations is its efficiency. Among them are the high pressure drop in the pipes and the expensive valve being used to measure the flowrate of the natural gas. In order to store the natural gas in the station, a compressor is used to compress the gas to 24000kPa. This way, the amount being stored in the station is able to meet the demand. The problem occurs when the natural gas is transferred to the vehicle.

During the transfer from the reservoir, which in this case is the compressor, to the opening of the receiver, in this case the car tank, a high pressure drop occurs. This pressure drop can very from 17000kPa to 23650kPa. Another pressure drop occurs during the transfer of natural gas from the opening of the receiver to the inside of the receiver. This drop can very from 300kPa to 7000kPa depending on the pressure of the receiver.

This pressure drop can be translated to energy loss to the system. Based on this study, equations were developed to quantify this energy loss. This equation will be able to get the energy loss in the system from the initial pressure and final pressure of the system .

1.3 OBJECTIVE AND SCOPE OF STUDY

1.3.1 Objective

The study is conducted in an open ended manner where the progress depends on the availability of time. Hence, more progress beyond the scope of the project is feasible and this study sets the pioneering work related this topic. From the problem statement, the main objectives of the project are identified as follows:

- To develop equation to calculate energy loss during transferring of NG to refueling station

- To develop equation to calculate energy loss in receiver tank due to expansion

- To test the equation using set of data to watch the trend of energy loss in the system

The general objectives of this FYP are as follows:

- To enhance student's skills in the process of organizing, researching and applying knowledge using the appropriate resources for research projects

- To assist students to apply theoretical knowledge to application of problems faced by the industry

- To train students to solving problems independently and presenting the findings through minimum guidance and supervision

1.3.2 Scope

As mention previously the study is an open – ended project. However the measure of success of the project depends on the achieved objectives within certain scope.

The scope of this study is limited to the energy loss during the transferring of natural gas from the reservoir to the receiver due to the pressure drop. The other factors that cause energy loss to the system will not be taken into account when developing the equations.

The system is divided into two sections. The first section will comprise from the reservoir till the opening of the receiver. The other section is the receiver tank itself. This two sections were divided because of different criterion that needed to be implement in the equations.

The data used to verify these equations were taken from test conducted in the PETRONAS natural gas refueling station. Based on the data the author was able to generate graphs to show the trend lines for energy loss in the system.

CHAPTER 2

LITERATURE REVIEW AND THEORY

2.1 NATURAL GAS

Natural gas is a clean safe and useful energy source. Natural gas is a fossil fuel. Natural gas can also be formed through the transformation of organic matter by tiny microorganisms. This type of methane is referred to as biogenic methane. Methanogens, tiny methane producing microorganisms, chemically break down organic matter to produce methane. These microorganisms are commonly found in areas near the surface of the earth that are void of oxygen. Natural gas is used across all sectors, in varying amounts. The graph below gives an idea of the proportion of natural gas use per sector

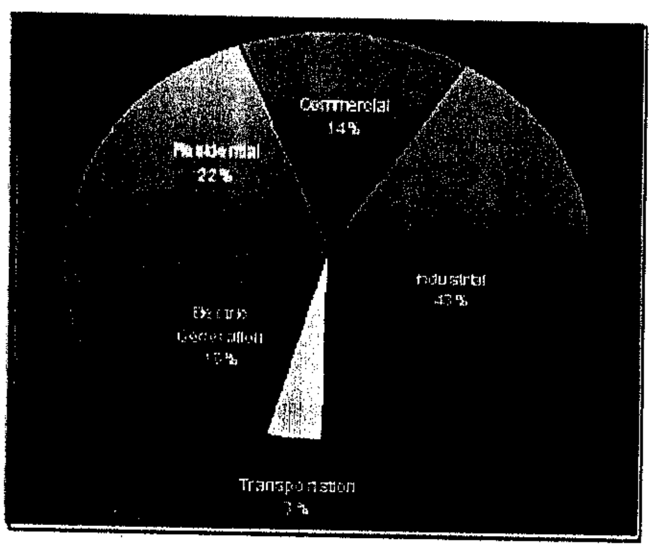


Figure 2.1 Natural Gas Usages

2.1.1 Natural Gas Composition

The composition of natural gas is not universally constant as it is normally drawn from several production fields. The composition from a particular source or at a particular end-user location can also vary from time. The table below will show the recommended composition of natural gas for vehicles.

Component	Tolerance	CAT Dual-Fuel	Cummins	Deere	Detroit	Mack
Hydrocarbons						
Methane	Minimum	88.0%	90%		88%	85%
Ethane	Maximum	6.0%	4%		6%	11%
C_3+	Maximum	3.0%				
Propane	Maximum		1.7%	5%	1.7%	9%
C_4+	Maximum		0.7%		0.3%	
C_6+	Maximum	0.2%				
Butane	Maximum			1%		5%
$C_2+C_3+C_4$						11%
Inerts (N_2, CO_2)	Range/ Max	1.5-4.5%	3.0% total			2% N_2 3%CO_2
Oxygen	Maximum	1.0%	0.5%			
Hydrogen	Maximum	0.1%	0.1%		0.1%	
CO	Maximum	0.1%	0.1%			
Sulfur	Maximum		0.001% by mass		22 ppm by mass	
Methanol	Maximum				0%	
$CO_2+N_2+O_2$	Maximum				4.5%	

Table 2.1Recommended gas composition ranges by some natural gas engine manufacturers

2.1.2 Natural Gas Properties

Natural gas properties also vary with time. Below is a table showing the recommended properties for natural gas vehicles

Property	Tolerance	CAT Dual-Fuel	Cummins	Deere	Detroit	Mack
Wobbe Index. (MJ/m^3)	Range		48.46 – 51.33		47.7-51.06	
Octane Rating (MON)	Minimum			118	115	
Methane Number (MN)	Minimum		80 (standard engines) 65 for Plus Technology			
Lower heating value	Minimum		43.7 MJ/kg for Plus Technology engines	33.74 MJ/m^3		
Higher heating value			36.3 MJ/m^3 (standard engines)			

Table 2.2 Recommended gas combustion properties by some natural gas engine manufacturers

2.2 COMPRESSIBLE FLUID FLOW

The compressibility of fluid is basically, a measure of the change in density that will be produced in the fluid by a specified change in pressure. Gases are, in general, highly compressible whereas most liquids have a very low compressibility. In a fluid flow, there are usually changes in the pressure associated with the changes in the velocity in the flow. These pressure changes will, in general, induce density changes which will have an influence on the flow.

2.2.1 Definitions and Basic Equations

Most of the compressible flows that occur in engineering practice can be adequately modeled as a flow through a duct or stream tube. The following assumptions were made in order to simplify the following equations. Actual engineering situations may be adequately represented by the mathematical models obtained within the limitations of the assumptions.

1. The flow is steady
2. The flow is one-dimensional
3. Velocity gradients within the a cross section are neglected
4. Friction is restricted to wall shear
5. Shaft work is zero
6. Gravitational effects are negligible
7. The fluid is an ideal gas at constant specific heat

The following basic relations are used

- Continuity Equation

The continuity equation is obtained by applying the principle of conservation of mass to flow through a control volume. The following example will be used to derive the equation

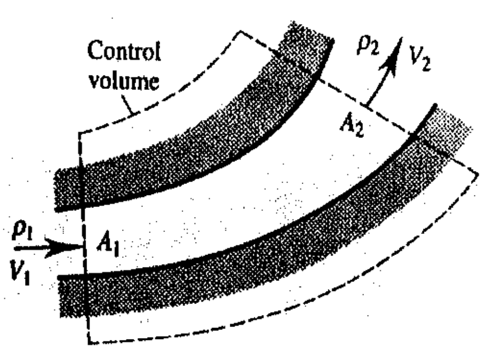


Figure 2.2 Control volume used in derivation of continuity equation

$$\dot{m}_1 = \dot{m}_2$$

$$\rho_1 V_1 A_1 = \rho_2 V_2 A_2$$

For the differentially short control volume

$$\rho VA = (\rho + d\rho)(V + dV)(A + dA)$$

Neglecting high order terms

$$VAd\rho + \rho AdV + \rho VdA = 0$$

Dividing this equation by ρVA then gives

$$\frac{d\rho}{\rho} + \frac{dV}{V} + \frac{dA}{A} = 0$$

Where

[p] = density

[V] = volume

[A] = area

- Steady Flow Energy Equation

This states that, for flow through the type of control volume considered above, if the fluid enters at section 1 with velocity V1 and with enthalpy,h1 per unit mass, and leaves through section 2 with velocity V2 and enthalpy h2 then

$$h_2 + \frac{V_2^2}{2} = h_1 + \frac{V_1^2}{2} + q - w$$

Since calorically perfect gases are being considered

$$h = c_p T$$

Hence the steady flow energy equation for the present purpose can be represented as

$$c_p T_2 + \frac{V_2^2}{2} = c_p T_1 + \frac{V_1^2}{2} + q$$

If the flow is adiabatic

$$c_p T_2 + \frac{V_2^2}{2} = c_p T_1 + \frac{V_1^2}{2}$$

- Mechanical Energy Balance

Friction manifests itself by the disappearance of mechanical energy. In frictional flow for compressible fluids

$$\frac{dp}{\rho} + d\left(\frac{\alpha \hat{V}^2}{2}\right) + gdZ + dh_f = 0$$

This equation is simplified by omitting the potential energy terms, noting that $\alpha_a = \alpha_b = 1.0$, u = V, and restricting the friction to wall shear. The equation then becomes

$$\frac{dp}{\rho} + d\left(\frac{u^2}{2}\right) + dh_{fs} = 0$$

- Equation of State

When applied between two points in a flow, this equation gives

$$\frac{p_1}{\rho_1 T_1} = \frac{p_2}{\rho_2 T_2}$$

When applied between inlet and the exit of a differentially short control volume, this equation becomes

$$\frac{p}{\rho T} = \frac{p + dp}{(\rho + d\rho)(T + dT)}$$

When higher order terms are neglected

$$\frac{dp}{p}-\frac{dT}{T}-\frac{d\rho}{\rho}=0$$

This equation shows how the changes in pressure, density, and temperature are interrelated in compressible flow

- Mach Number

The Mach number, Ma is defined as the ratio of u, speed of the fluid, to a, the speed of sound in the fluid

$$Ma=\frac{u}{a}$$

If Ma<1 the flow is said to be subsonic, whereas if Ma>1 the flow is said to be supersonic. If the Ma is near 1 and there are regions of both subsonic and supersonic flow, the flow is said to be transonic. If the Ma number is very high (Ma>5) it is said to be hypersonic.

The speed of sound in perfect gas is given by

$$a=\sqrt{\frac{\gamma p}{\rho}}=\sqrt{\gamma RT}$$

2.2.2 Processes of Compressible Flow

The flow processes to be considered in this chapter are shown in the figure below. It is assumed that a very large supply of gas at a specified temperature and pressure and at zero velocity and Mach number is available. The origin of the gas is called the reservoir, the temperature and pressure of the gas in the reservoir are called reservoir conditions.

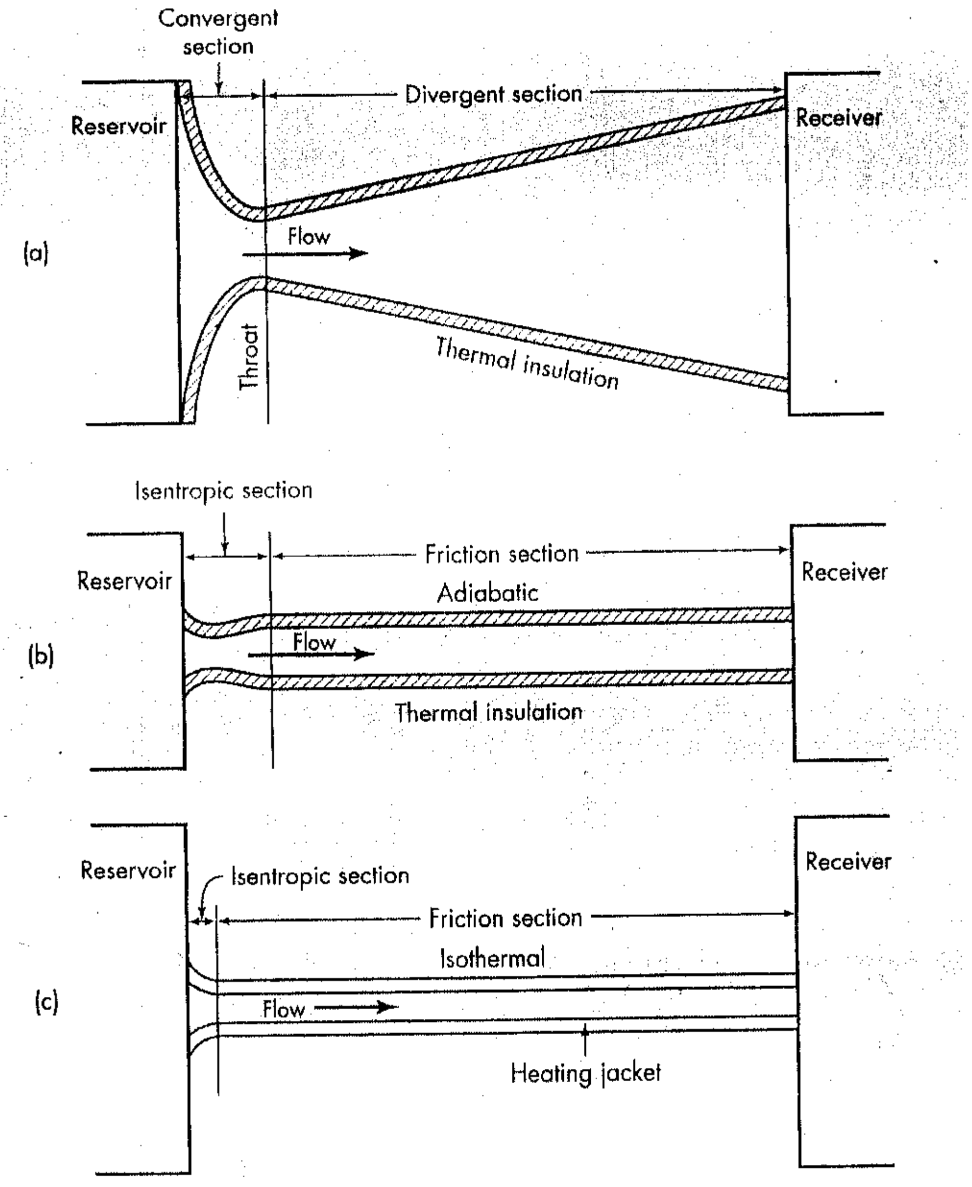


Figure 2.3 (a)Isentropic flow in a convergent-divergent nozzle. (b) Adiabatic friction flow. (c) Isothermal friction flow

From the reservoir the gas is assumed to flow without friction loss at the entrance, into and through the pipe. The gas leaves the pipe at the definite temperature, velocity and pressure and goes into an exhaust receiver

Within the pipe any one of the following processes may occur

1. Isentropic expansion. In this process the cross-sectional area of the conduit must change, and the process is described as one of the variable area. Such a process is shown diagrammatically in Fig

2. Adiabatic friction flow through a pipe of constant cross section. This process is irreversible and the entropy of the gas increases. Q=0. This process is shown in Fig

3. Isothermal friction flow through a pipe of constant cross sectional area, accompanied by a flow of heat through the pipe wall sufficient to keep the temperature constant. This process is non adiabatic and non isentropic. This process is shown in Fig

In this project, the flow was defined as adiabatic friction flow. The mass velocity which is used in this project was derived according to the conditions of this flow

Mach number for compressible friction flow

$$Ma^2 = \frac{\rho u^2}{\gamma p} = \frac{u^2}{\gamma TR/M}$$

$$Ma^2 = \frac{(\rho u)^2}{\rho^2 \gamma TR/M} = \frac{G^2}{\rho^2 \gamma TR/M}$$

Therefore

$$G = \rho Ma\sqrt{\frac{\gamma TR}{M}}$$

Where

[G]	= mass velocity, kg/m2
[ρ]	= density of fluid, kg/m3
[Ma]	= mach number, u/a
[γ]	= ratio of specific heat, c_p/c_v
[T]	= temperature, K
[R]	= gas law constant, J/gmol.K
[M]	= molecular weight of fluid

2.3 THERMODYNAMICS

The interrelationship among temperature, pressure and volume of a gas is often complicated. When ideal gas model is assumed, there are three main equations

$$pv = RT$$

$$u = u(T)$$

$$h = h(T) = u(T) + RT$$

For a gas obeying the ideal gas model, specific internal energy depends only on the temperature. Hence the specific heat is also a function of temperature

$$c_v = \frac{du}{dT}$$

Similarly, for a gas obeying the ideal gas model, the specific enthalpy depends only on the temperature

$$c_p(T) = \frac{dh}{dT}$$

$$dh = c_p(T)dT$$

There other specific heat functions when ideal gas situations are assumed. One of the function is

$$\frac{c_p}{R} = a + bT + cT^2 + dT^{-2}$$

Values of the constants a,b,c, and d are usually listed in tables for several gases in the temperature range 300K to 1000K.

CHAPTER 3

METHODOLOGY AND PROJECT WORK

3.1 PROJECT OVERVIEW

This project involved research and modeling work which uses the ability to manipulate a few compressible fluid flow and thermodynamics equations. For this project, MATLAB was used to develop the model for the energy loss in the pipes. This section is the part between the reservoir and the opening of the receiver. In order to develop the model, first a equation had to identified. This equation will later be manipulated to show the energy loss in a system due to the pressure drop. Once the equation was developed, the next step was to validate it. Due to inadequate data, this equation could be partially proofed. The data needed was the pressure at various points of the pipe. Only inlet and outlet pressure of the pipe was obtained.

For the receiver, thermodynamics was used to find the energy loss in the system. Here using the basic thermodynamics equation to find the enthalpy for various different pressures, the energy loss for the system was calculated. The data provided to proof this equation was sufficient because it provided the pressure for every second during the filling process for the receiver.

Once the equation was tested, various graphs were plotted to show the trend lines of energy loss in the system. The energy loss pattern can be studied on the basis of different initial pressures in the system.

3.11 Tools Required

For this project work, the modeling of the equation will utilize computer software. For modeling purpose, Matlab Version 6.1 will be used. As for data analysis, Microsoft® Excel is used. To develop the equation in the first section Matlab software was used. The process of construction, and testing of the model will be done with this software. Microsoft® Excel used to perform basic calculation such as cumulative energy loss in the system.

3.2 METHODOLOGY OF THE PROJECT

The project work can be summarized in the figure below. These are only the major steps in the project. The figure below shows the methodology in developing the model for this project

Data collection and processing

↓

Develop energy equation for pipeline

↓

Writing programming codes

↓

Developing energy loss equations for the receiver

↓

Inserting data to obtain results

↓

Combining equations to find energy loss for the system

↓

model validation

3.3 PROJECT WORK

3.3.1 Data Collection and Processing

The data used in this project to validate the equation was collected from a pressure test conducted in one of the PETRONAS refueling station. This data was classified according to the different initial pressure in the opening of the receiver and also the initial pressure in the receiver tank. The experiment was to fill the receiver tank with the specified initial pressure and observe to pressure changes in the system. The pressure was recorded for every second of the duration it took to refill the receiver tank. The table below will summarize the data received.

End Pipe pressure, kPa	Pressure in receiver. kPa
8114.52	7020.711
8114.52	3508.59
8114.52	704.15
8114.52	101.325
1145.26	199.79
229.05	171.78
229.05	145.36

Table 3.1 Different sets of data received

There were also varying initial reservoir pressures

1. 24800kPa
2. 3500kPa
3. 700kPa

3.3.2 Developing Energy Loss Equation for Pipeline

In this section, the energy loss equation for pipeline was derived. Before that could be done, a proper understanding of the system had to be achieved. A conceptual design of the system was drawn. In this design, the two sections can be clearly seen. With this design, the author was able to derive the appropriate equations based on the given criteria. Below is the diagram showing the system.

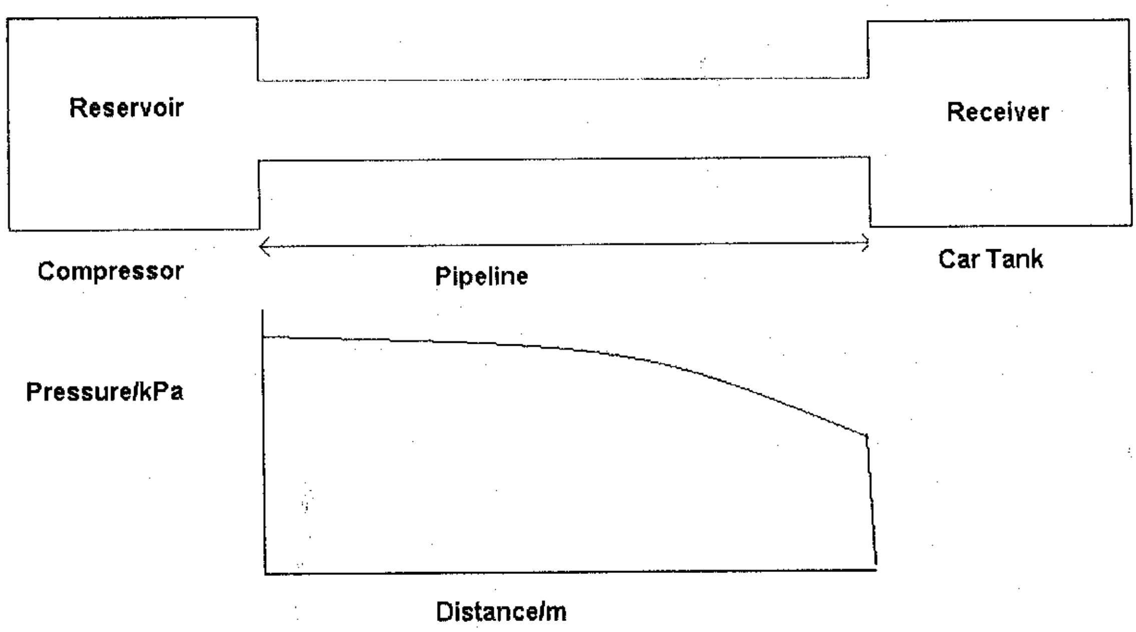


Figure 3.1 Conceptual design of system

Along with the system, a graph of the pressure Vs distance was included to show the theoretical pattern of the pressure drop.

Another conceptual design of the pipeline was drawn to clearly show the section

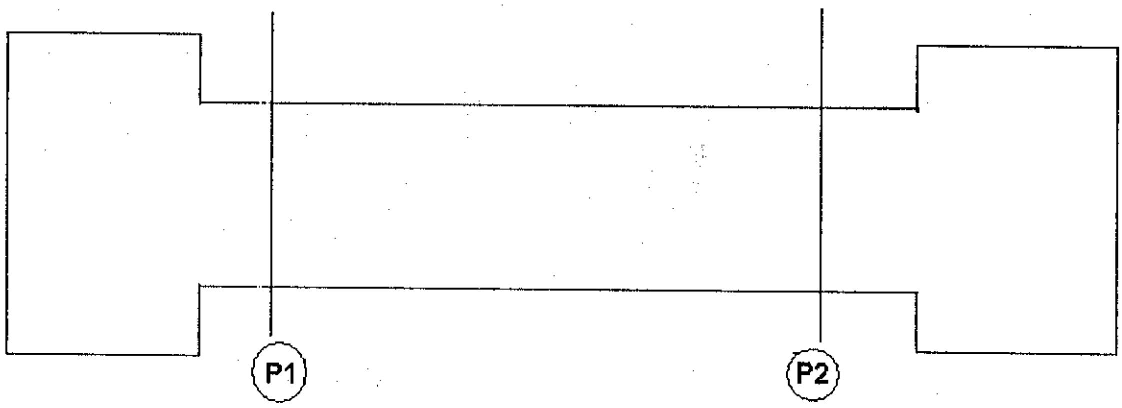


Figure 3.2 Conceptual design of pipeline

In order to derive the equation for energy loss in the pipeline, compressible fluid flow laws were applied. From the mechanical energy balance equation, the desired equation was achieved. Below is the mechanical energy balance that was used:

$$\frac{dp}{\rho} + d\left(\frac{V^2 \alpha}{2}\right) + gdZ + dh_f = 0$$

Where

[dp] = pressure drop in the system, kPa

[p] = density of the fluid, kg/m3

[V] = fluid velocity, m/s

[a] = kinetic energy correction factor

[g] = gravitational acceleration, m/s2

[Z] = height above datum plane, m

[h] = friction loss, N.m/g

Several assumptions were made in order to derive the equation

1. Flow in the pipeline is adiabatic friction flow
2. Mach no. in the pipeline is constant
3. There is no elevation in the pipeline

With these assumptions, the energy loss equation was derived. The detail derivation will be explained in the results section.

3.3.3 Modeling the equation in MATLAB

After the equation was derived, it was placed into MATLAB. Below is the initial codes written for the equation derived

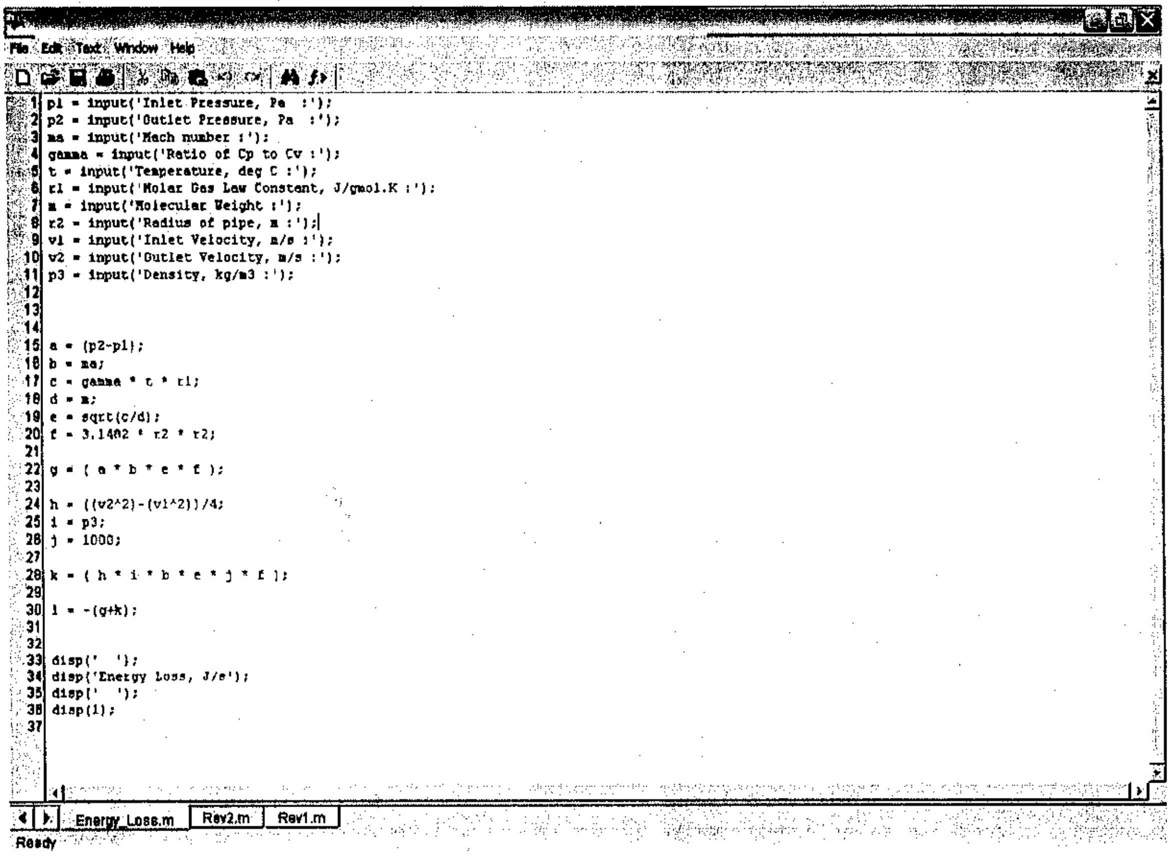


Figure 3.3 Programming codes for pipeline equation

With this program the user will have to key in the variable to get the energy loss of the system. In order to make the program easier, several values were made constant. Those values are :

Mach number: 1

Gamma: 1.3

Temp: 30 deg C

Gas constant: 8.3143

Molecular weight: 17.02

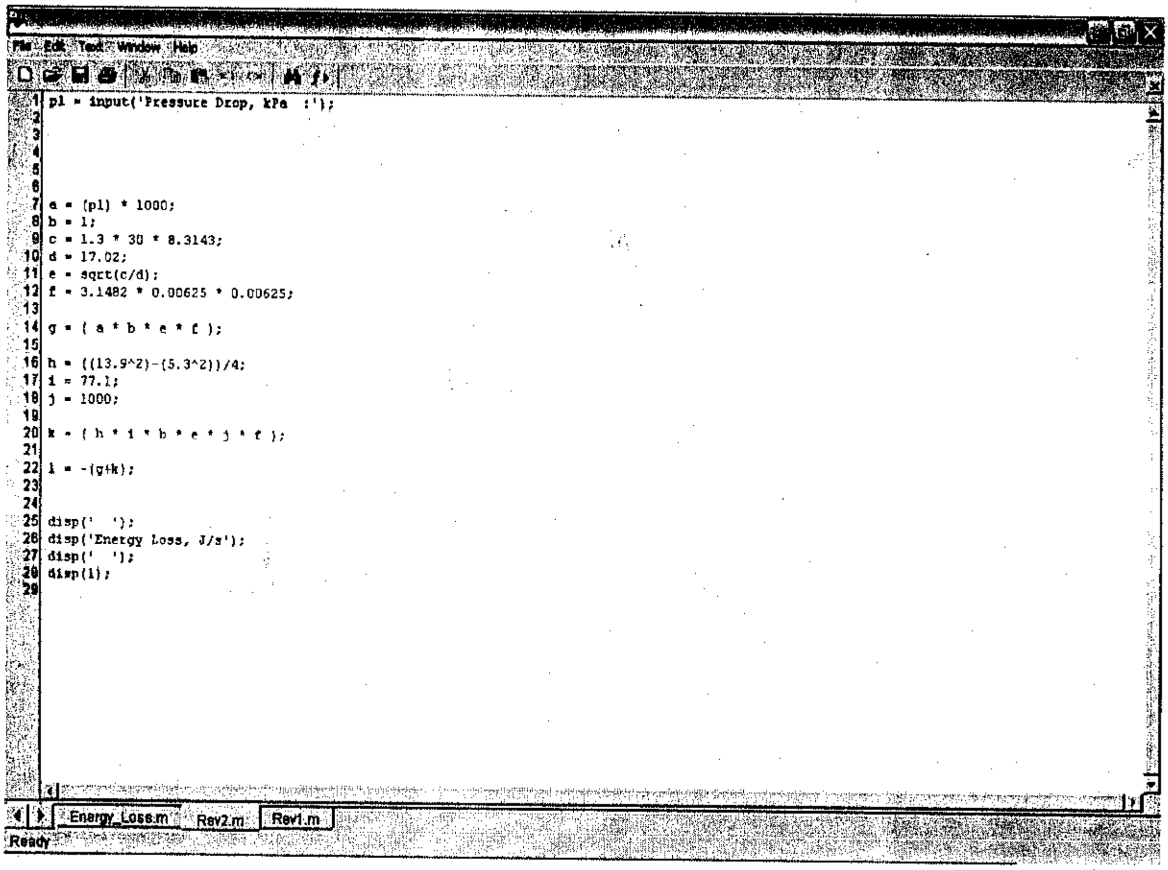
Pipe radius: 0.00625 m

Inlet velocity: 5.3 m/s

Outlet velocity: 13.9 m/s

Density: 77.1 kg/m3

Now the equation has only one variable. The program above was revised.




```
pl = input('Pressure Drop, kPa  :');




a = (pl) * 1000;
b = 1;
c = 1.3 * 30 * 8.3143;
d = 17.02;
e = sqrt(c/d);
f = 3.1482 * 0.00625 * 0.00625;

g = ( a * b * e * f );

h = ((13.9^2)-(5.3^2))/4;
i = 77.1;
j = 1000;

k = ( h * i * b * e * j * f );

l = -(g+k);


disp('  ');
disp('Energy Loss, J/s');
disp('  ');
disp(l);
```

Figure 3.3 Revision of programming codes after elimination of variables

This program will only ask for the pressure drop value. In return it will give the energy loss in the pipeline.

3.3.4 Developing Energy Loss Equation for Receiver

For this section, only the receiver tank was taken into account. This meant that the compressible fluid flow conditions used to model the first section's equation cannot be applied. The conceptual design for this section is as follows:

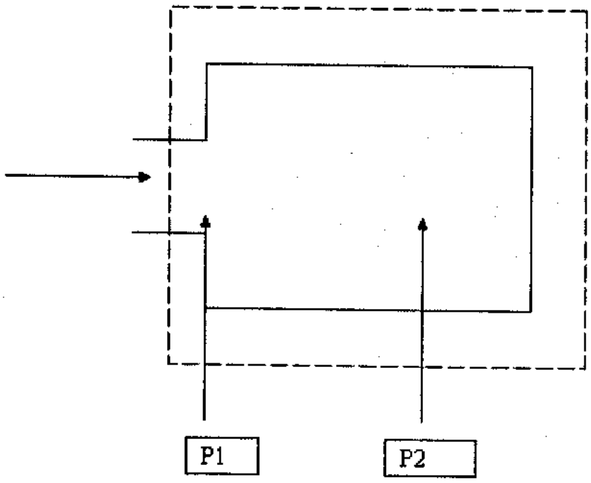


Figure 3.4 Conceptual design of receiver

Here the receiver is tank located in the back of the car. The dotted lines indicate the system boundary. The arrow shows the flow of natural gas into the receiver tank. In this section the initial pressure, P1 is taken at the end of the pipe or the opening of the receiver tank. P2 is taken at a sufficient distance downstream of the sudden are change so that the local effects (eddies at the corners) can be assumed as having evened out.

To solve this problem, the author decided to correlate the enthalpy change in the system with the energy loss of the system. The equation that was found by doing literature review was:

$$E = m * H(T,P)$$

Where
[E] = energy in system
[m]= mass of NG in receiver
[H]=specific enthalpy in function of pressure and temperature

There were two methods to get the enthalpy of the system.

1.Finding the enthalpy from the thermodynamics properties table. In this case since the percentage of methane is high in natural gas, the superheated methane table was chosen

2.Calculation the enthalpy from the given equations. These equations are stated below and will be derived in the results section

$$dh = c_p(T)dT$$

where c_p

$$\frac{c_p^o}{R} = a + bT + cT^2 + dT^{-2}$$

3.3.5 Using Equation and Data to Produce Grahpical Interpertation

Once the equation was complete, the data was entered and several graphs were produced to show the trend lines of energy loss in the receiver. Below is a sample data that was used in this project:

Time, s	End pipe pressure, kPa	Pressure in receiver, kPa	ΔP, kPa
0	101.33	101.33	0
1	1145.257456	199.7904248	945
2	1145.257456	298.2558496	847
3	1145.257456	396.7212744	749
4	1145.257456	495.1866992	650
5	1145.257456	593.652124	552
6	1145.257456	692.1175488	453
7	1145.257456	790.5829736	355
8	1145.257456	889.0483984	256
9	1145.257456	987.5138232	158
10	1145.257456	1085.979248	59

Table 3.2 Sample data for 3500-101

Note:
Source pressure: 3500kPa
Receiver's initial pressure: 101kPa

Here the source pressure is the reservoir pressure. It can be clearly seen as the receiver tank fills up the pressure drop in the system decreases.

The graphs for all the data will be presented and discussed in chapter 4.

3.3.6 Combining the equations

This part of the project could not be completed due to time constrain. This part objective was to write a program that will be able to compute the total energy loss of the system with the values of the following variables.

1. Reservoir pressure
2. End of pipe pressure
3. Receiver pressure

CHAPTER 4

RESULTS AND DISCUSSION

4.1 DATA PROCESSING AND CLASSIFICATION

The raw data obtained, needed to be classified according initial pressures of the end of pipe and receiver. With this classification, it made it easier to perform analysis on the energy loss. Below is few sample data that has been classified according to the criteria stated above. The real data which will be placed in the appendix runs until the pressure drop is 0. Also to be noted is the pressure drop between the source and the end of pipe. Although it is not shown, there is a constant pressure drop between the source and the end of pipe.

Time, s	End pipe pressure, kPa	Pressure in receiver, kPa	ΔP, kPa
0	101.325	101.325	0
1	8114.52127	7020.711237	1094
2	8114.52127	7046.921034	1068
3	8114.52127	7073.13083	1041
4	8114.52127	7099.340626	1015
5	8114.52127	7125.550423	989
6	8114.52127	7151.760219	963
7	8114.52127	7177.970015	937
8	8114.52127	7204.179812	910
9	8114.52127	7230.389608	884
10	8114.52127	7256.599404	858
11	8114.52127	7282.809201	832
12	8114.52127	7309.018997	806
13	8114.52127	7335.228794	779
14	8114.52127	7361.43859	753
15	8114.52127	7387.648386	727

Table 4.1 Sample of data when source is 24800kPa and receiver is 7000kPa

Time, s	End pipe pressure, kPa	Pressure in receiver, kPa	ΔP, kPa
0	101.325	101.325	0
1	8114.52127	3508.598526	4606
2	8114.52127	3534.808322	4580
3	8114.52127	3561.018119	4554
4	8114.52127	3587.227915	4527
5	8114.52127	3613.437711	4501
6	8114.52127	3639.647508	4475
7	8114.52127	3665.857304	4449
8	8114.52127	3692.0671	4422
9	8114.52127	3718.276897	4396
10	8114.52127	3744.486693	4370
11	8114.52127	3770.696489	4344
12	8114.52127	3796.906286	4318
13	8114.52127	3823.116082	4291
14	8114.52127	3849.325879	4265
15	8114.52127	3875.535675	4239

Table 4.2 Sample of data when source is 24800kPa and receiver is 3500kPa

Time, s	End pipe pressure, kPa	Pressure in receiver, kPa	ΔP, kPa
0	101.325	101.325	0
1	8114.52127	704.1503161	7410
2	8114.52127	730.3601125	7384
3	8114.52127	756.5699088	7358
4	8114.52127	782.7797052	7332
5	8114.52127	808.9895015	7306
6	8114.52127	835.1992979	7279
7	8114.52127	861.4090942	7253
8	8114.52127	887.6188906	7227
9	8114.52127	913.828687	7201
10	8114.52127	940.0384833	7174
11	8114.52127	966.2482797	7148
12	8114.52127	992.458076	7122
13	8114.52127	1018.667872	7096
14	8114.52127	1044.877669	7070
15	8114.52127	1071.087465	7043

Table 4.3 Sample of data when source is 24800kPa and receiver is 700kPa

Time, s	End pipe pressure, kPa	Pressure in receiver, kPa	ΔP, kPa
0	101.325	101.325	0
1	8114.52127	363.4229635	7751
2	8114.52127	389.6327599	7725
3	8114.52127	415.8425562	7699
4	8114.52127	442.0523526	7672
5	8114.52127	468.2621489	7646
6	8114.52127	494.4719453	7620
7	8114.52127	520.6817417	7594
8	8114.52127	546.891538	7568
9	8114.52127	573.1013344	7541
10	8114.52127	599.3111307	7515
11	8114.52127	625.5209271	7489
12	8114.52127	651.7307234	7463
13	8114.52127	677.9405198	7437
14	8114.52127	704.1503161	7410
15	8114.52127	730.3601125	7384

Table 4.4 Sample of data when source is 24800kPa and receiver is 101kPa

Time, s	End pipe pressure, kPa	Pressure in receiver, kPa	ΔP, kPa
0	101.33	101.33	0
1	1145.257456	199.7904248	945
2	1145.257456	298.2558496	847
3	1145.257456	396.7212744	749
4	1145.257456	495.1866992	650
5	1145.257456	593.652124	552
6	1145.257456	692.1175488	453
7	1145.257456	790.5829736	355
8	1145.257456	889.0483984	256
9	1145.257456	987.5138232	158
10	1145.257456	1085.979248	59

Table 4.5 Sample of data when source is 3500kPa and receiver is 170kPa

The data tabulated above will be used for the receiver section calculations. As for the pipeline, the data received will be sufficient to produce an energy loss profile across the pipeline.

4.2 DERIVATION OF EQUATION TO CALCULATE ENERGY LOSS IN PIPELINE

The derivation of the required equation depends upon the manipulation of the basic equation mechanical energy balance

$$\frac{dp}{\rho} + d(\frac{\alpha \hat{V}^2}{2}) + gdZ + dh_f = 0$$

Assumptions:

1. Flow in the pipeline is adiabatic friction flow
2. Mach no. in the pipeline is constant
3. There is no elevation in the pipeline

In the light of this assumptions, this equation is simplified by omitting the potential energy terms, noting that $\alpha_a = \alpha_b = 1.0$, u = V, and restricting the friction to wall shear. The equation then becomes

$$\frac{dp}{\rho} + d(\frac{u^2}{2}) + dh_{fs} = 0$$

Rearranging the equation gives

$$\frac{dp}{\rho} + d(\frac{u^2}{2}) = -dh_{fs} \qquad (1)$$

Finding mass velocity for adiabatic friction flow

Mach number for compressible friction flow

$$Ma^2 = \frac{\rho u^2}{\gamma p} = \frac{u^2}{\gamma TR / M}$$

$$Ma^2 = \frac{(\rho u)^2}{\rho^2 \gamma TR / M} = \frac{G^2}{\rho^2 \gamma TR / M}$$

Therefore

$$G = \rho Ma \sqrt{\frac{\gamma TR}{M}} \qquad (2)$$

Where

[G] = mass velocity, kg/m2

[ρ] = density of fluid, kg/m3

[Ma] = mach number, u/a

[γ] = ratio of specific heat, c_p / c_v

[T] = temperature, K

[R] = gas law constant, J/gmol.K

[M] = molecular weight of fluid

Equation (2)*(1)

$$\frac{dp}{\rho} * G + d(\frac{u^2}{2}) * G = -dh_{fs} * G$$

$$(P_2 - P_1)(Ma\sqrt{\frac{\gamma TR}{M}}) + \frac{(V_2^2 - V_1^2)}{4}(\rho Ma\sqrt{\frac{\gamma TR}{M}}) = -dh_{fs}(\rho Ma\sqrt{\frac{\gamma TR}{M}})$$

Making the right side in terms of energy, E

$$(P_2 - P_1)(Ma\sqrt{\frac{\gamma TR}{M}})*(A) + \frac{(V_2^2 - V_1^2)}{4}(\rho Ma\sqrt{\frac{\gamma TR}{M}})*(A)*(1000) = -dh_{fs}(\rho Ma\sqrt{\frac{\gamma TR}{M}})*(A)*(1$$

The right hand side will equal to energy/sec, E

$$E = -[(P_2 - P_1)(Ma\sqrt{\frac{\gamma TR}{M}})*(A) + \frac{(V_2^2 - V_1^2)}{4}(\rho Ma\sqrt{\frac{\gamma TR}{M}})*(A)*(1000)]$$

4.3 EQUATION TO CALCULATE THE ENERGY LOSS IN THE RECEIVER

As mentioned in the earlier section, the compressible fluid flow equations cannot be manipulated to find the energy loss in the receiver. The author believes the pressure drop in the receiver is due to expansion. The method used to calculate the energy loss in the receiver was the change in enthalpy. Enthalpy is a function of temperature and pressure. Therefore the changes of pressure in the system will change the enthalpy. From these changes, the energy change can also be calculated. By subtracting the enthalpy at the opening of the receiver with the enthalpy in the system, the energy loss to the system can be found.

The first task in hand was to develop a equation that could relate energy to enthalpy. From the literature review, the following relation was found

$E = m * H(T,P)$

Where

[E] = energy in system

[m]= mass of NG in receiver

[H]=specific enthalpy in function of pressure and temperature

With the data given, the mass at every second recorded can be found by multiplying the mass flowrate with the corresponding time.

The enthalpy, h of the system can be calculated by two methods

1. Using the thermodynamics properties table

   First it was assumed that the methane thermodynamics properties will be very close to that of natural gas. Natural gas has a very high percentage of methane (94%). This discrepancy in the results was because the natural gas thermodynamics properties table could not be found. This was mainly due to the lack of time. The table used was the superheated methane table. In order to use the table, the temperature in the receiver had to be assumed constant. The temperature used was 300K. The pressure values were either taken directly from the table or interpolated.

2. Deriving the equation from the thermodynamics equations

   In order to compute the enthalpy directly from the equation, several thermodynamics equations will have to be manipulated.

   For a gas obeying the ideal gas model,

$$dh = c_p(T)dT$$

$$c_p(T) = \frac{dh}{dT} \qquad (1)$$

Heat capacities in ideal gas state can also be calculated with

$$\frac{c_p}{R} = a + bT + cT^2 + dT^{-2} \qquad (2)$$

Combining equation (1) and (2)

$$\frac{dh}{dT} = R(a + bT + cT^2 + dT^{-2})$$

Integrating of the equation

$$h = R(aT + \frac{bT^2}{2} + \frac{cT^3}{3} - dT)$$

Since it is in a ideal gas state

$$PV = nRT$$

$$T = \frac{PV}{nR}$$

Hence the equation becomes

$$h = R[a(\frac{PV}{nR}) + \frac{b(\frac{PV}{nR})^2}{2} + \frac{c(\frac{PV}{nR})^3}{3} - d(\frac{PV}{nR})]$$

The two variables in this equation is the pressure and number of moles in the system

Based on the two methods to calculate enthalpy, the use of the thermodynamics table was chosen. This is because when the equation manipulated was used it was found that the enthalpy values were too high. This could be attributed by the fact that ideal gas equation was used when the proper method would have been to use the real gas equation. The addition of the compressibility factor, Z would have given a more accurate value of the enthalpy.

4.4 GRAPHICAL INTERPERTATION OF DATA

Several graphs showing the tread lines of energy loss in the system was produced. This graphs show only the energy loss in the receiver section. All of it has the same source/reservoir pressure but varying receiver pressure.

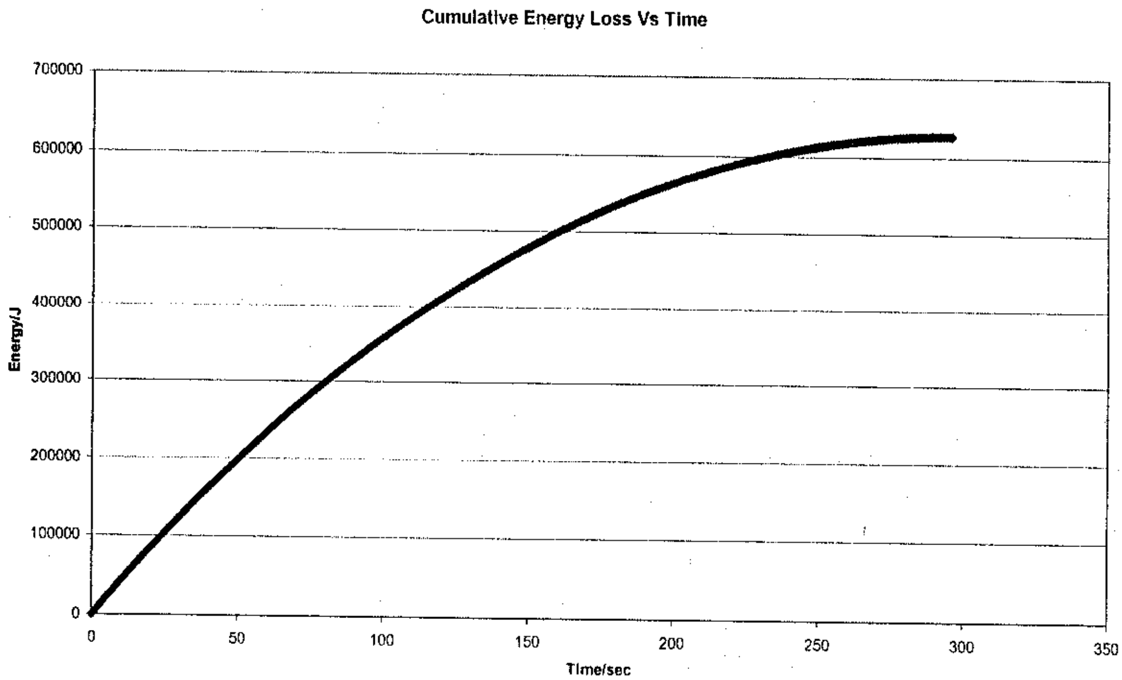


Figure 4.1 Cumulative Energy Loss Vs Time for 24800-101

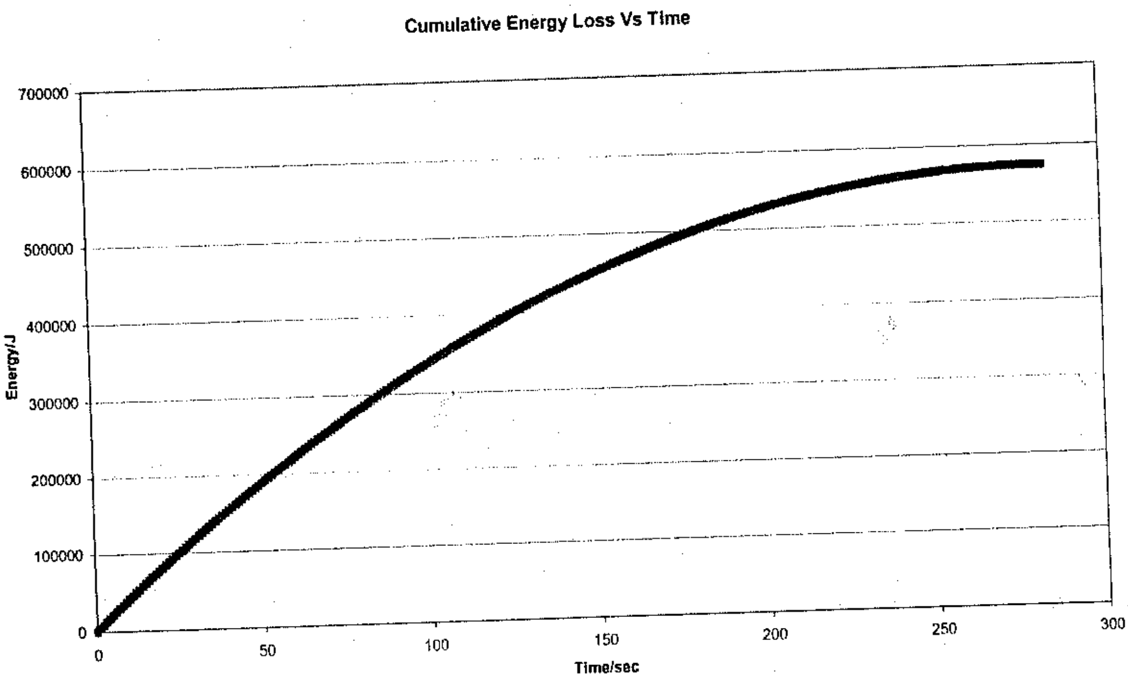


Figure 4.2 Cumulative Energy Loss Vs Time for 24800-700

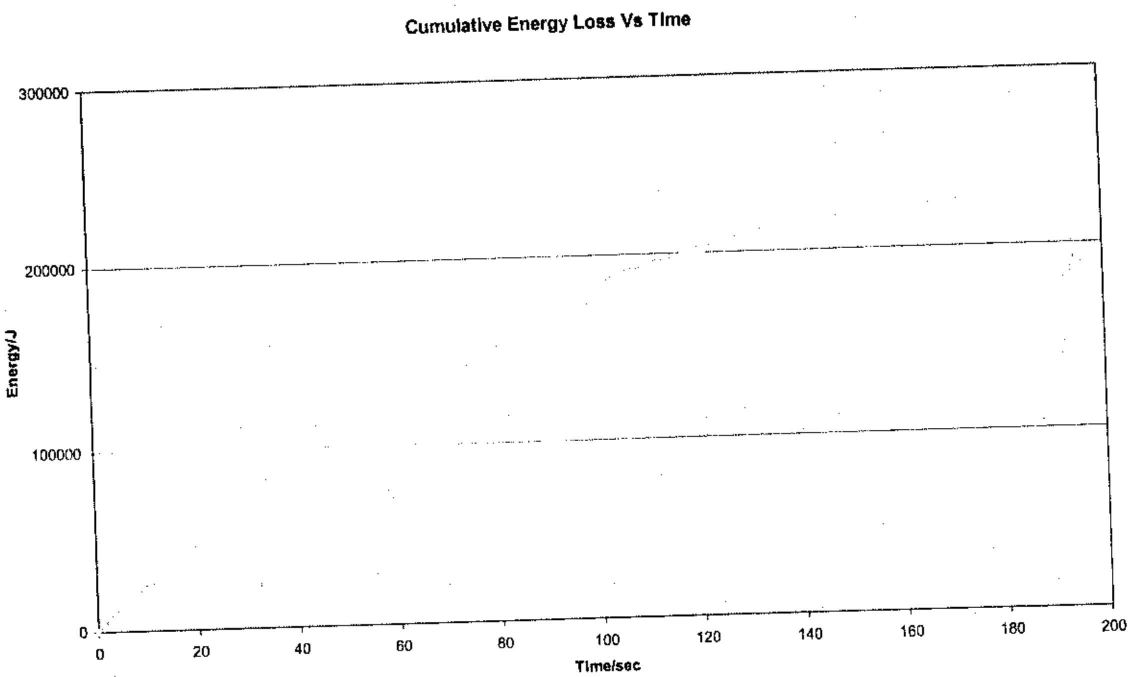


Figure 4.3 Cumulative Energy Loss Vs Time for 24800-3500

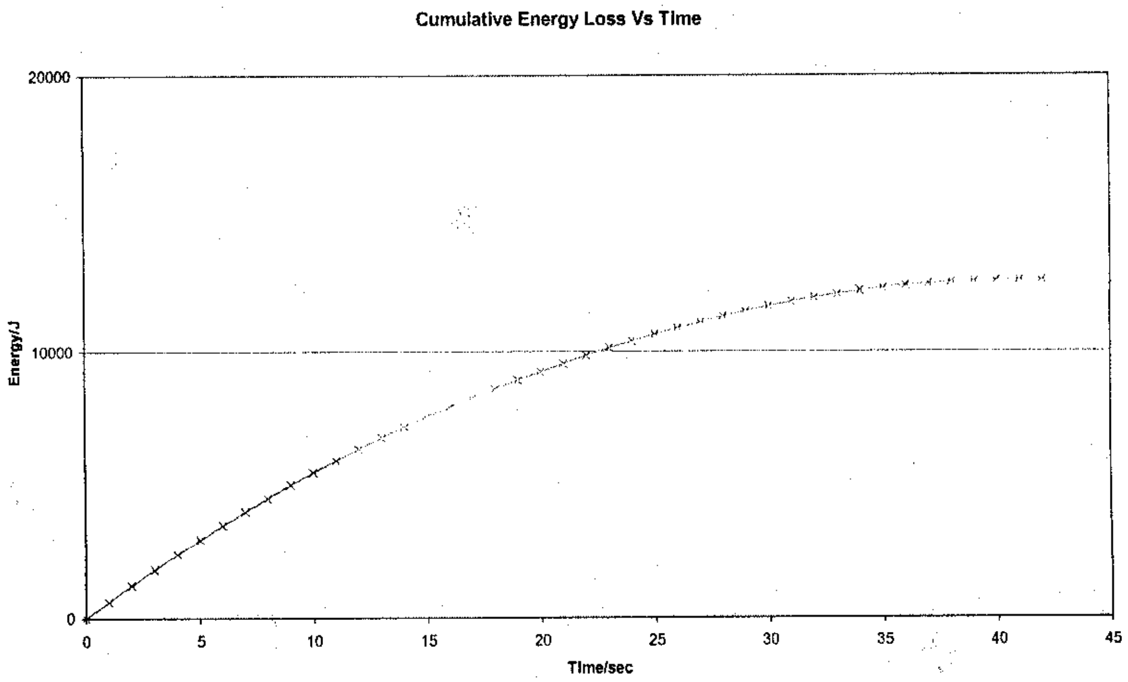


Figure 4.4 Cumulative Energy Loss Vs Time for 24800-7000

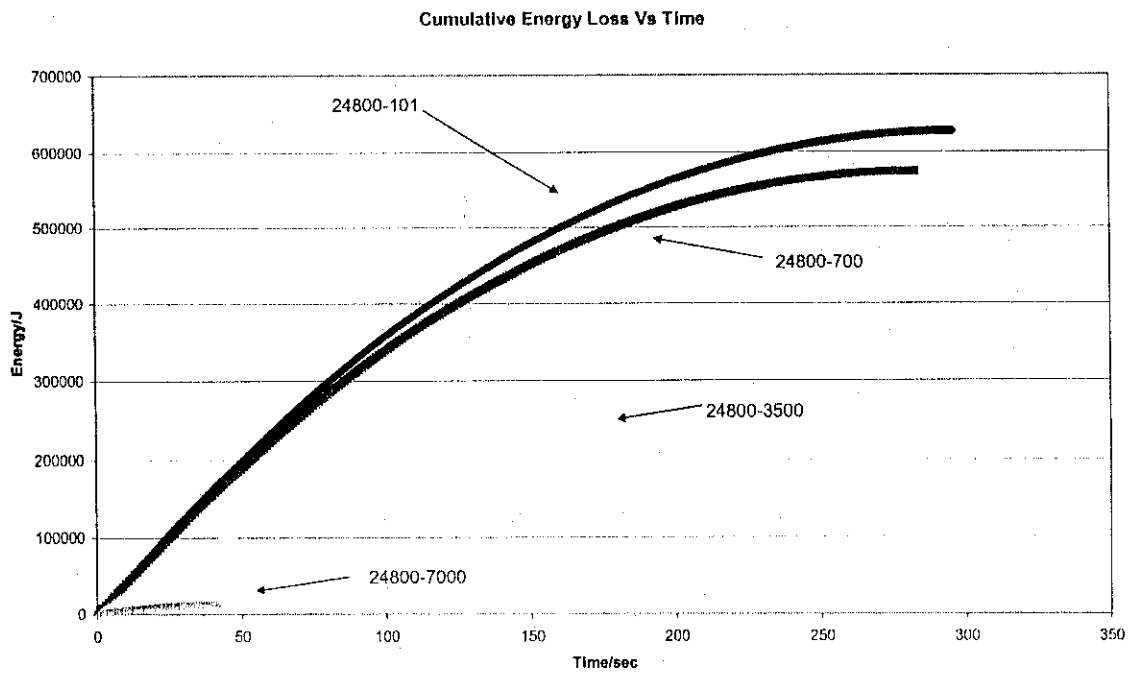


Figure 1.5 Cumulative Energy Loss Vs Time for various pressure

The graph above show the relationship between energy loss and the time it took for the receiver to completely fill. The receiver is judged full when the pressure in the receiver equals the pressure in the end of the pipe. That is why when the initial pressure in the receiver is high (i.e. 7000kPa), it takes a shorter period to fill up then when the initial pressure in the receiver is low (i.e. 101kPa). Also it can be seen that the energy loss is much larger when the pressure drop is significant. From this analysis, it can be said that in order to reduce the energy loss during refueling, the minimum pressure in the tank be increased. The 24800kPa in the graph represents the source pressure. Although the end of pipe pressure is not stated, it is the same for all four experiments (8000kPa).

The energy loss for this system can be noted to be very high. This value could be inaccurate due to several reasons. During the modeling of the equation, a few assumptions were taken into account. One of it was that the temperature in the receiver is held constant. This assumption could cause the difference in the actual energy loss and the computed one. Another reason could be the assumption that it was in and ideal gas state. If there no time constrain, the proper method would have been to deal with a real gas state.

4.5 SAMPLE CALCULATION USING THE MATLAB PROGRAM

There is not enough data to create graph for the energy loss profile in the pipeline. The figure below will show the program compute the energy loss when inserted the following values

Source/Reservoir Pressure, kPa	End of Pipe Pressure. kPa
24800	7000
24800	3500
24800	700
24800	101

Table 4.6 Data used for pipeline eqaution testing

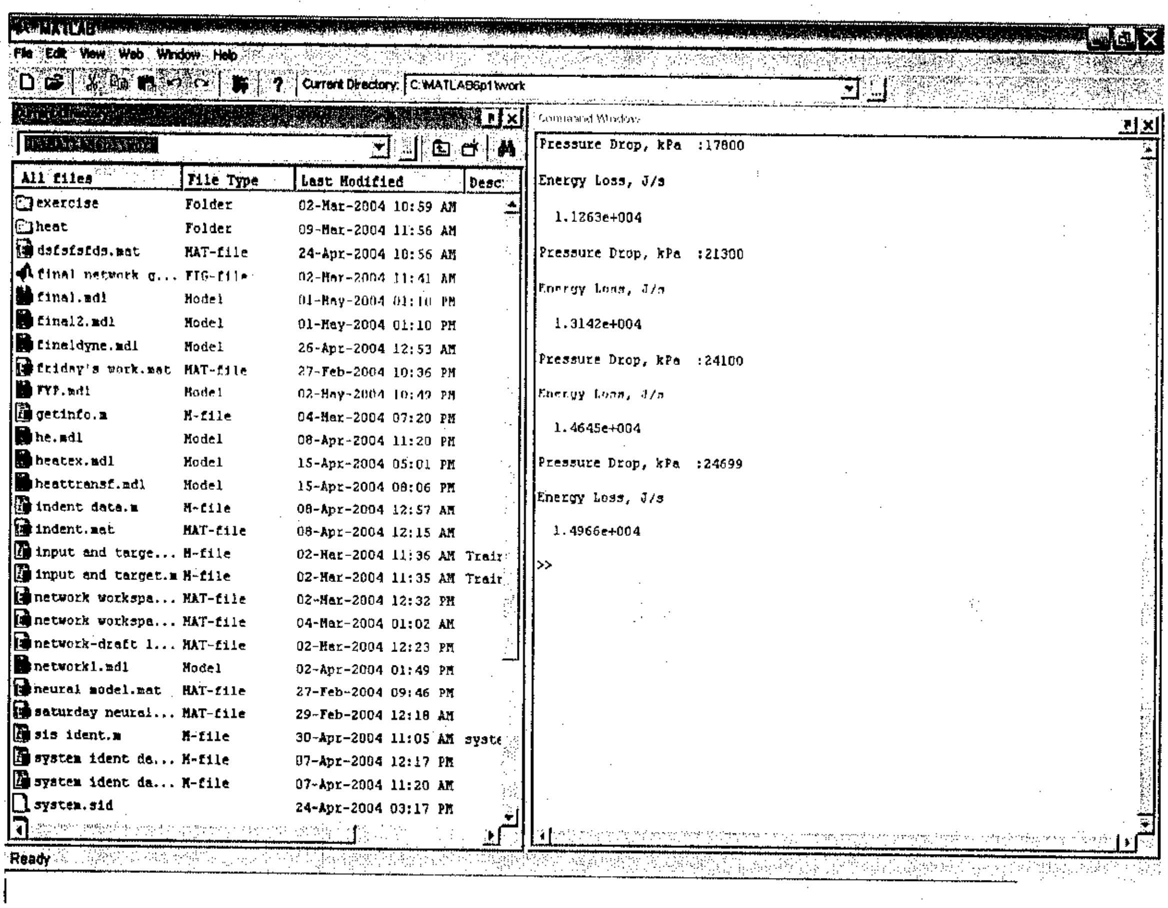


Figure 4.6 Results from pipeline equation

Based on the results presented, it can be seen that as the pressure drop increases the energy loss in the pipeline increases. This means the formula for the pipeline holds true to the theory. This energy loss could have been caused by the friction against the wall of the pipe.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

Overall, the study on the relationship of pressure drop in a pipeline and refueling process for a natural gas metering station with the energy loss in the system has resulted in the derivation of two equations. These two equations give the amount of energy loss in a system based on the respective criteria. In order to derive these further assumptions were made for simplification purposes.

The first equation derived was for the pipeline in the system. Here the flow was assumed adiabatic friction flow. The resulting equation is shown below

$$E = -[(P_2 - P_1)(Ma\sqrt{\frac{\gamma TR}{M}}) * (A) + \frac{(V_2^2 - V_1^2)}{4}(\rho Ma\sqrt{\frac{\gamma TR}{M}}) * (A) * (1000)]$$

Once the constants were identified, the variables in the equation are the initial pressure at the source/reservoir, P1 and the end of pipe pressure, P2. Although the data was limited, the results from running the equation showed that as the pressure drop is becomes larger, the energy loss to the system increases. $\Delta P\uparrow$, $E_{loss}\uparrow$

The second equation derived was for the receiver tank. The study was conducted while the tank was refueling. Initially the data showed that the pressure was quite large, but the difference reduced as the tank filled up. Based on the trend lines created, the energy loss to the system also reduced as the pressure drop reduced. Again it could be concluded for a closed tank, the energy loss to the system increases as the pressure drop increases.

The equation developed is

$$E = m * H(T,P)$$ Nomenclature

5.2 RECOMMENDATION

Some recommendations can be suggested to improve the future work on this study to obtain more precise equations to calculate the energy loss in this system.

what data

For the pipeline section, more data is required. In order to obtain a energy profile over the pipeline distance, pressure has to be taken in equal intervals of length. This would help create a better understanding of the relationship between pressure drop and energy loss. Also many variables were made into constants in order to obtain the energy loss in the pipeline. More data on these variables will also further improve the preciseness of the equation. The flow in this pipeline was taken as adiabatic friction flow. This statement is true for most of the pipe but not at the opening and at the end. The flow in these areas is isentropic expansion. Taking this into account when developing further models would give better accuracy.

For the receiver section, the results would be more accurate if real gas state was assumed rather then ideal gas state. This would mean taking into account the compressibility factor, Z. Also the use of the natural gas thermodynamics properties table would be more precise then the methane thermodynamics properties table.

? factor

and pressure range use in the study

REFERENCES

G.J.SHARPE, Solving *Problems in : Fluid Dynamics*, Longman Scientific and Technical; 1994, New York

WILLIAM F.HUGHES and JOHN A.BRIGHTON, *Fluid Dynamics Third Edition*, McGraw-Hill ; 1999, New York

DONALD F. YOUNG, BRUCE R. MUNSON and THEODORE H. OKIISHI, *A Brief Introduction to Fluid Dynamics Second Edition*, John Wiley and Sons; 2001, United States

OOSTHUIZEN, PATRICK H. and CARSCALLEN, WILLIAM E., *Compressible Fluid Flow,* McGraw-Hill; 1997, Singapore

MCCABE, SMITH and HARRIOT, *Unit Operations of Chemical Engineering 6th Edition,* McGraw-Hill; 2001, New York

HANSELMAN, DUANE and LITTLEFIELD, BRUCE, *Mastering MATLAB 6: A comprehensive Tutorial and Reference,* Prentice Hall; 2001, New Jersey

ROBERT H. PERRY and DON W. GREEN, *Perry's Chemical Engineers' Handbook Seventh Edition*, McGraw-Hill; 1997, United States

MICHAEL J. MORAN and HOWARD N. SHAPIRO, *Fundamental of Engineering Thermodynamics Fourth Edition*, John Wiley and Sons; 2000, United States

JACK WINNICK, *Chemical Engineering Thermodynamics*, John Wiley and Sons; 1997, United States

APPENDICES

Appendix 5.1: Raw Data on Pressure Drop

Appendix 5.2 Superheated Methane Thermodynamics Table

ne, s	End pipe pressure, kPa	Pressure in receiver, kPa	ΔP, kPa
0	101.325	101.325	0
1	8114.52127	363.4229635	7751
2	8114.52127	389.6327599	7725
3	8114.52127	415.8425562	7699
4	8114.52127	442.0523526	7672
5	8114.52127	468.2621489	7646
6	8114.52127	494.4719453	7620
7	8114.52127	520.6817417	7594
8	8114.52127	546.891538	7568
9	8114.52127	573.1013344	7541
10	8114.52127	599.3111307	7515
11	8114.52127	625.5209271	7489
12	8114.52127	651.7307234	7463
13	8114.52127	677.9405198	7437
14	8114.52127	704.1503161	7410
15	8114.52127	730.3601125	7384
16	8114.52127	756.5699088	7358
17	8114.52127	782.7797052	7332
18	8114.52127	808.9895015	7306
19	8114.52127	835.1992979	7279
20	8114.52127	861.4090942	7253
21	8114.52127	887.6188906	7227
22	8114.52127	913.828687	7201
23	8114.52127	940.0384833	7174
24	8114.52127	966.2482797	7148
25	8114.52127	992.458076	7122
26	8114.52127	1018.667872	7096
27	8114.52127	1044.877669	7070
28	8114.52127	1071.087465	7043
29	8114.52127	1097.297261	7017
30	8114.52127	1123.507058	6991
31	8114.52127	1149.716854	6965
32	8114.52127	1175.92665	6939
33	8114.52127	1202.136447	6912
34	8114.52127	1228.346243	6886
35	8114.52127	1254.55604	6860
36	8114.52127	1280.765836	6834
37	8114.52127	1306.975632	6808
38	8114.52127	1333.185429	6781
39	8114.52127	1359.395225	6755
40	8114.52127	1385.605021	6729
41	8114.52127	1411.814818	6703
42	8114.52127	1438.024614	6676
43	8114.52127	1464.23441	6650
44	8114.52127	1490.444207	6624
45	8114.52127	1516.654003	6598
46	8114.52127	1542.863799	6572

47	8114.52127	1569.073596	6545
48	8114.52127	1595.283392	6519
49	8114.52127	1621.493188	6493
50	8114.52127	1647.702985	6467
51	8114.52127	1673.912781	6441
52	8114.52127	1700.122578	6414
53	8114.52127	1726.332374	6388
54	8114.52127	1752.54217	6362
55	8114.52127	1778.751967	6336
56	8114.52127	1804.961763	6310
57	8114.52127	1831.171559	6283
58	8114.52127	1857.381356	6257
59	8114.52127	1883.591152	6231
60	8114.52127	1909.800948	6205
61	8114.52127	1936.010745	6179
62	8114.52127	1962.220541	6152
63	8114.52127	1988.430337	6126
64	8114.52127	2014.640134	6100
65	8114.52127	2040.84993	6074
66	8114.52127	2067.059727	6047
67	8114.52127	2093.269523	6021
68	8114.52127	2119.479319	5995
69	8114.52127	2145.689116	5969
70	8114.52127	2171.898912	5943
71	8114.52127	2198.108708	5916
72	8114.52127	2224.318505	5890
73	8114.52127	2250.528301	5864
74	8114.52127	2276.738097	5838
75	8114.52127	2302.947894	5812
76	8114.52127	2329.15769	5785
77	8114.52127	2355.367486	5759
78	8114.52127	2381.577283	5733
79	8114.52127	2407.787079	5707
80	8114.52127	2433.996875	5681
81	8114.52127	2460.206672	5654
82	8114.52127	2486.416468	5628
83	8114.52127	2512.626265	5602
84	8114.52127	2538.836061	5576
85	8114.52127	2565.045857	5549
86	8114.52127	2591.255654	5523
87	8114.52127	2617.46545	5497
88	8114.52127	2643.675246	5471
89	8114.52127	2669.885043	5445
90	8114.52127	2696.094839	5418
91	8114.52127	2722.304635	5392
92	8114.52127	2748.514432	5366
93	8114.52127	2774.724228	5340
94	8114.52127	2800.934024	5314
95	8114.52127	2827.143821	5287
96	8114.52127	2853.353617	5261
97	8114.52127	2879.563413	5235
98	8114.52127	2905.77321	5209

99	8114.52127	2931.983006	5183
100	8114.52127	2958.192803	5156
101	8114.52127	2984.402599	5130
102	8114.52127	3010.612395	5104
103	8114.52127	3036.822192	5078
104	8114.52127	3063.031988	5051
105	8114.52127	3089.241784	5025
106	8114.52127	3115.451581	4999
107	8114.52127	3141.661377	4973
108	8114.52127	3167.871173	4947
109	8114.52127	3194.08097	4920
110	8114.52127	3220.290766	4894
111	8114.52127	3246.500562	4868
112	8114.52127	3272.710359	4842
113	8114.52127	3298.920155	4816
114	8114.52127	3325.129951	4789
115	8114.52127	3351.339748	4763
116	8114.52127	3377.549544	4737
117	8114.52127	3403.759341	4711
118	8114.52127	3429.969137	4685
119	8114.52127	3456.178933	4658
120	8114.52127	3482.38873	4632
121	8114.52127	3508.598526	4606
122	8114.52127	3534.808322	4580
123	8114.52127	3561.018119	4554
124	8114.52127	3587.227915	4527
125	8114.52127	3613.437711	4501
126	8114.52127	3639.647508	4475
127	8114.52127	3665.857304	4449
128	8114.52127	3692.0671	4422
129	8114.52127	3718.276897	4396
130	8114.52127	3744.486693	4370
131	8114.52127	3770.696489	4344
132	8114.52127	3796.906286	4318
133	8114.52127	3823.116082	4291
134	8114.52127	3849.325879	4265
135	8114.52127	3875.535675	4239
136	8114.52127	3901.745471	4213
137	8114.52127	3927.955268	4187
138	8114.52127	3954.165064	4160
139	8114.52127	3980.37486	4134
140	8114.52127	4006.584657	4108
141	8114.52127	4032.794453	4082
142	8114.52127	4059.004249	4056
143	8114.52127	4085.214046	4029
144	8114.52127	4111.423842	4003
145	8114.52127	4137.633638	3977
146	8114.52127	4163.843435	3951
147	8114.52127	4190.053231	3924
148	8114.52127	4216.263027	3898
149	8114.52127	4242.472824	3872
150	8114.52127	4268.68262	3846

151	8114.52127	4294.892417	3820
152	8114.52127	4321.102213	3793
153	8114.52127	4347.312009	3767
154	8114.52127	4373.521806	3741
155	8114.52127	4399.731602	3715
156	8114.52127	4425.941398	3689
157	8114.52127	4452.151195	3662
158	8114.52127	4478.360991	3636
159	8114.52127	4504.570787	3610
160	8114.52127	4530.780584	3584
161	8114.52127	4556.99038	3558
162	8114.52127	4583.200176	3531
163	8114.52127	4609.409973	3505
164	8114.52127	4635.619769	3479
165	8114.52127	4661.829565	3453
166	8114.52127	4688.039362	3426
167	8114.52127	4714.249158	3400
168	8114.52127	4740.458955	3374
169	8114.52127	4766.668751	3348
170	8114.52127	4792.878547	3322
171	8114.52127	4819.088344	3295
172	8114.52127	4845.29814	3269
173	8114.52127	4871.507936	3243
174	8114.52127	4897.717733	3217
175	8114.52127	4923.927529	3191
176	8114.52127	4950.137325	3164
177	8114.52127	4976.347122	3138
178	8114.52127	5002.556918	3112
179	8114.52127	5028.766714	3086
180	8114.52127	5054.976511	3060
181	8114.52127	5081.186307	3033
182	8114.52127	5107.396103	3007
183	8114.52127	5133.6059	2981
184	8114.52127	5159.815696	2955
185	8114.52127	5186.025493	2928
186	8114.52127	5212.235289	2902
187	8114.52127	5238.445085	2876
188	8114.52127	5264.654882	2850
189	8114.52127	5290.864678	2824
190	8114.52127	5317.074474	2797
191	8114.52127	5343.284271	2771
192	8114.52127	5369.494067	2745
193	8114.52127	5395.703863	2719
194	8114.52127	5421.91366	2693
195	8114.52127	5448.123456	2666
196	8114.52127	5474.333252	2640
197	8114.52127	5500.543049	2614
198	8114.52127	5526.752845	2588
199	8114.52127	5552.962642	2562
200	8114.52127	5579.172438	2535
201	8114.52127	5605.382234	2509
202	8114.52127	5631.592031	2483

203	8114.52127	5657.801827	2457
204	8114.52127	5684.011623	2431
205	8114.52127	5710.22142	2404
206	8114.52127	5736.431216	2378
207	8114.52127	5762.641012	2352
208	8114.52127	5788.850809	2326
209	8114.52127	5815.060605	2299
210	8114.52127	5841.270401	2273
211	8114.52127	5867.480198	2247
212	8114.52127	5893.689994	2221
213	8114.52127	5919.89979	2195
214	8114.52127	5946.109587	2168
215	8114.52127	5972.319383	2142
216	8114.52127	5998.52918	2116
217	8114.52127	6024.738976	2090
218	8114.52127	6050.948772	2064
219	8114.52127	6077.158569	2037
220	8114.52127	6103.368365	2011
221	8114.52127	6129.578161	1985
222	8114.52127	6155.787958	1959
223	8114.52127	6181.997754	1933
224	8114.52127	6208.20755	1906
225	8114.52127	6234.417347	1880
226	8114.52127	6260.627143	1854
227	8114.52127	6286.836939	1828
228	8114.52127	6313.046736	1801
229	8114.52127	6339.256532	1775
230	8114.52127	6365.466328	1749
231	8114.52127	6391.676125	1723
232	8114.52127	6417.885921	1697
233	8114.52127	6444.095718	1670
234	8114.52127	6470.305514	1644
235	8114.52127	6496.51531	1618
236	8114.52127	6522.725107	1592
237	8114.52127	6548.934903	1566
238	8114.52127	6575.144699	1539
239	8114.52127	6601.354496	1513
240	8114.52127	6627.564292	1487
241	8114.52127	6653.774088	1461
242	8114.52127	6679.983885	1435
243	8114.52127	6706.193681	1408
244	8114.52127	6732.403477	1382
245	8114.52127	6758.613274	1356
246	8114.52127	6784.82307	1330
247	8114.52127	6811.032866	1303
248	8114.52127	6837.242663	1277
249	8114.52127	6863.452459	1251
250	8114.52127	6889.662256	1225
251	8114.52127	6915.872052	1199
252	8114.52127	6942.081848	1172
253	8114.52127	6968.291645	1146
254	8114.52127	6994.501441	1120

255	8114.52127	7020.711237	1094
256	8114.52127	7046.921034	1068
257	8114.52127	7073.13083	1041
258	8114.52127	7099.340626	1015
259	8114.52127	7125.550423	989
260	8114.52127	7151.760219	963
261	8114.52127	7177.970015	937
262	8114.52127	7204.179812	910
263	8114.52127	7230.389608	884
264	8114.52127	7256.599404	858
265	8114.52127	7282.809201	832
266	8114.52127	7309.018997	806
267	8114.52127	7335.228794	779
268	8114.52127	7361.43859	753
269	8114.52127	7387.648386	727
270	8114.52127	7413.858183	701
271	8114.52127	7440.067979	674
272	8114.52127	7466.277775	648
273	8114.52127	7492.487572	622
274	8114.52127	7518.697368	596
275	8114.52127	7544.907164	570
276	8114.52127	7571.116961	543
277	8114.52127	7597.326757	517
278	8114.52127	7623.536553	491
279	8114.52127	7649.74635	465
280	8114.52127	7675.956146	439
281	8114.52127	7702.165942	412
282	8114.52127	7728.375739	386
283	8114.52127	7754.585535	360
284	8114.52127	7780.795332	334
285	8114.52127	7807.005128	308
286	8114.52127	7833.214924	281
287	8114.52127	7859.424721	255
288	8114.52127	7885.634517	229
289	8114.52127	7911.844313	203
290	8114.52127	7938.05411	176
291	8114.52127	7964.263906	150
292	8114.52127	7990.473702	124
293	8114.52127	8016.683499	98
294	8114.52127	8042.893295	72
295	8114.52127	8069.103091	45
296	8114.52127	8114.52127	0

e:
rce pressure: 24800kPa
eiver's initial pressure: 101kPa

Time, s	End pipe pressure, kPa	Pressure in receiver, kPa	ΔP, kPa
0	101.325	101.325	0
1	8114.52127	704.1503161	7410
2	8114.52127	730.3601125	7384
3	8114.52127	756.5699088	7358
4	8114.52127	782.7797052	7332
5	8114.52127	808.9895015	7306
6	8114.52127	835.1992979	7279
7	8114.52127	861.4090942	7253
8	8114.52127	887.6188906	7227
9	8114.52127	913.828687	7201
10	8114.52127	940.0384833	7174
11	8114.52127	966.2482797	7148
12	8114.52127	992.458076	7122
13	8114.52127	1018.667872	7096
14	8114.52127	1044.877669	7070
15	8114.52127	1071.087465	7043
16	8114.52127	1097.297261	7017
17	8114.52127	1123.507058	6991
18	8114.52127	1149.716854	6965
19	8114.52127	1175.92665	6939
20	8114.52127	1202.136447	6912
21	8114.52127	1228.346243	6886
22	8114.52127	1254.55604	6860
23	8114.52127	1280.765836	6834
24	8114.52127	1306.975632	6808
25	8114.52127	1333.185429	6781
26	8114.52127	1359.395225	6755
27	8114.52127	1385.605021	6729
28	8114.52127	1411.814818	6703
29	8114.52127	1438.024614	6676
30	8114.52127	1464.23441	6650
31	8114.52127	1490.444207	6624
32	8114.52127	1516.654003	6598
33	8114.52127	1542.863799	6572
34	8114.52127	1569.073596	6545
35	8114.52127	1595.283392	6519
36	8114.52127	1621.493188	6493
37	8114.52127	1647.702985	6467
38	8114.52127	1673.912781	6441
39	8114.52127	1700.122578	6414
40	8114.52127	1726.332374	6388
41	8114.52127	1752.54217	6362
42	8114.52127	1778.751967	6336
43	8114.52127	1804.961763	6310
44	8114.52127	1831.171559	6283
45	8114.52127	1857.381356	6257
46	8114.52127	1883.591152	6231

47	8114.52127	1909.800948	6205
48	8114.52127	1936.010745	6179
49	8114.52127	1962.220541	6152
50	8114.52127	1988.430337	6126
51	8114.52127	2014.640134	6100
52	8114.52127	2040.84993	6074
53	8114.52127	2067.059727	6047
54	8114.52127	2093.269523	6021
55	8114.52127	2119.479319	5995
56	8114.52127	2145.689116	5969
57	8114.52127	2171.898912	5943
58	8114.52127	2198.108708	5916
59	8114.52127	2224.318505	5890
60	8114.52127	2250.528301	5864
61	8114.52127	2276.738097	5838
62	8114.52127	2302.947894	5812
63	8114.52127	2329.15769	5785
64	8114.52127	2355.367486	5759
65	8114.52127	2381.577283	5733
66	8114.52127	2407.787079	5707
67	8114.52127	2433.996875	5681
68	8114.52127	2460.206672	5654
69	8114.52127	2486.416468	5628
70	8114.52127	2512.626265	5602
71	8114.52127	2538.836061	5576
72	8114.52127	2565.045857	5549
73	8114.52127	2591.255654	5523
74	8114.52127	2617.46545	5497
75	8114.52127	2643.675246	5471
76	8114.52127	2669.885043	5445
77	8114.52127	2696.094839	5418
78	8114.52127	2722.304635	5392
79	8114.52127	2748.514432	5366
80	8114.52127	2774.724228	5340
81	8114.52127	2800.934024	5314
82	8114.52127	2827.143821	5287
83	8114.52127	2853.353617	5261
84	8114.52127	2879.563413	5235
85	8114.52127	2905.77321	5209
86	8114.52127	2931.983006	5183
87	8114.52127	2958.192803	5156
88	8114.52127	2984.402599	5130
89	8114.52127	3010.612395	5104
90	8114.52127	3036.822192	5078
91	8114.52127	3063.031988	5051
92	8114.52127	3089.241784	5025
93	8114.52127	3115.451581	4999
94	8114.52127	3141.661377	4973
95	8114.52127	3167.871173	4947
96	8114.52127	3194.08097	4920
97	8114.52127	3220.290766	4894
98	8114.52127	3246.500562	4868

99	8114.52127	3272.710359	4842
100	8114.52127	3298.920155	4816
101	8114.52127	3325.129951	4789
102	8114.52127	3351.339748	4763
103	8114.52127	3377.549544	4737
104	8114.52127	3403.759341	4711
105	8114.52127	3429.969137	4685
106	8114.52127	3456.178933	4658
107	8114.52127	3482.38873	4632
108	8114.52127	3508.598526	4606
109	8114.52127	3534.808322	4580
110	8114.52127	3561.018119	4554
111	8114.52127	3587.227915	4527
112	8114.52127	3613.437711	4501
113	8114.52127	3639.647508	4475
114	8114.52127	3665.857304	4449
115	8114.52127	3692.0671	4422
116	8114.52127	3718.276897	4396
117	8114.52127	3744.486693	4370
118	8114.52127	3770.696489	4344
119	8114.52127	3796.906286	4318
120	8114.52127	3823.116082	4291
121	8114.52127	3849.325879	4265
122	8114.52127	3875.535675	4239
123	8114.52127	3901.745471	4213
124	8114.52127	3927.955268	4187
125	8114.52127	3954.165064	4160
126	8114.52127	3980.37486	4134
127	8114.52127	4006.584657	4108
128	8114.52127	4032.794453	4082
129	8114.52127	4059.004249	4056
130	8114.52127	4085.214046	4029
131	8114.52127	4111.423842	4003
132	8114.52127	4137.633638	3977
133	8114.52127	4163.843435	3951
134	8114.52127	4190.053231	3924
135	8114.52127	4216.263027	3898
136	8114.52127	4242.472824	3872
137	8114.52127	4268.68262	3846
138	8114.52127	4294.892417	3820
139	8114.52127	4321.102213	3793
140	8114.52127	4347.312009	3767
141	8114.52127	4373.521806	3741
142	8114.52127	4399.731602	3715
143	8114.52127	4425.941398	3689
144	8114.52127	4452.151195	3662
145	8114.52127	4478.360991	3636
146	8114.52127	4504.570787	3610
147	8114.52127	4530.780584	3584
148	8114.52127	4556.99038	3558
149	8114.52127	4583.200176	3531
150	8114.52127	4609.409973	3505

151	8114.52127	4635.619769	3479
152	8114.52127	4661.829565	3453
153	8114.52127	4688.039362	3426
154	8114.52127	4714.249158	3400
155	8114.52127	4740.458955	3374
156	8114.52127	4766.668751	3348
157	8114.52127	4792.878547	3322
158	8114.52127	4819.088344	3295
159	8114.52127	4845.29814	3269
160	8114.52127	4871.507936	3243
161	8114.52127	4897.717733	3217
162	8114.52127	4923.927529	3191
163	8114.52127	4950.137325	3164
164	8114.52127	4976.347122	3138
165	8114.52127	5002.556918	3112
166	8114.52127	5028.766714	3086
167	8114.52127	5054.976511	3060
168	8114.52127	5081.186307	3033
169	8114.52127	5107.396103	3007
170	8114.52127	5133.6059	2981
171	8114.52127	5159.815696	2955
172	8114.52127	5186.025493	2928
173	8114.52127	5212.235289	2902
174	8114.52127	5238.445085	2876
175	8114.52127	5264.654882	2850
176	8114.52127	5290.864678	2824
177	8114.52127	5317.074474	2797
178	8114.52127	5343.284271	2771
179	8114.52127	5369.494067	2745
180	8114.52127	5395.703863	2719
181	8114.52127	5421.91366	2693
182	8114.52127	5448.123456	2666
183	8114.52127	5474.333252	2640
184	8114.52127	5500.543049	2614
185	8114.52127	5526.752845	2588
186	8114.52127	5552.962642	2562
187	8114.52127	5579.172438	2535
188	8114.52127	5605.382234	2509
189	8114.52127	5631.592031	2483
190	8114.52127	5657.801827	2457
191	8114.52127	5684.011623	2431
192	8114.52127	5710.22142	2404
193	8114.52127	5736.431216	2378
194	8114.52127	5762.641012	2352
195	8114.52127	5788.850809	2326
196	8114.52127	5815.060605	2299
197	8114.52127	5841.270401	2273
198	8114.52127	5867.480198	2247
199	8114.52127	5893.689994	2221
200	8114.52127	5919.89979	2195
201	8114.52127	5946.109587	2168
202	8114.52127	5972.319383	2142

203	8114.52127	5998.52918	2116
204	8114.52127	6024.738976	2090
205	8114.52127	6050.948772	2064
206	8114.52127	6077.158569	2037
207	8114.52127	6103.368365	2011
208	8114.52127	6129.578161	1985
209	8114.52127	6155.787958	1959
210	8114.52127	6181.997754	1933
211	8114.52127	6208.20755	1906
212	8114.52127	6234.417347	1880
213	8114.52127	6260.627143	1854
214	8114.52127	6286.836939	1828
215	8114.52127	6313.046736	1801
216	8114.52127	6339.256532	1775
217	8114.52127	6365.466328	1749
218	8114.52127	6391.676125	1723
219	8114.52127	6417.885921	1697
220	8114.52127	6444.095718	1670
221	8114.52127	6470.305514	1644
222	8114.52127	6496.51531	1618
223	8114.52127	6522.725107	1592
224	8114.52127	6548.934903	1566
225	8114.52127	6575.144699	1539
226	8114.52127	6601.354496	1513
227	8114.52127	6627.564292	1487
228	8114.52127	6653.774088	1461
229	8114.52127	6679.983885	1435
230	8114.52127	6706.193681	1408
231	8114.52127	6732.403477	1382
232	8114.52127	6758.613274	1356
233	8114.52127	6784.82307	1330
234	8114.52127	6811.032866	1303
235	8114.52127	6837.242663	1277
236	8114.52127	6863.452459	1251
237	8114.52127	6889.662256	1225
238	8114.52127	6915.872052	1199
239	8114.52127	6942.081848	1172
240	8114.52127	6968.291645	1146
241	8114.52127	6994.501441	1120
242	8114.52127	7020.711237	1094
243	8114.52127	7046.921034	1068
244	8114.52127	7073.13083	1041
245	8114.52127	7099.340626	1015
246	8114.52127	7125.550423	989
247	8114.52127	7151.760219	963
248	8114.52127	7177.970015	937
249	8114.52127	7204.179812	910
250	8114.52127	7230.389608	884
251	8114.52127	7256.599404	858
252	8114.52127	7282.809201	832
253	8114.52127	7309.018997	806
254	8114.52127	7335.228794	779

255	8114.52127	7361.43859	753
256	8114.52127	7387.648386	727
257	8114.52127	7413.858183	701
258	8114.52127	7440.067979	674
259	8114.52127	7466.277775	648
260	8114.52127	7492.487572	622
261	8114.52127	7518.697368	596
262	8114.52127	7544.907164	570
263	8114.52127	7571.116961	543
264	8114.52127	7597.326757	517
265	8114.52127	7623.536553	491
266	8114.52127	7649.74635	465
267	8114.52127	7675.956146	439
268	8114.52127	7702.165942	412
269	8114.52127	7728.375739	386
270	8114.52127	7754.585535	360
271	8114.52127	7780.795332	334
272	8114.52127	7807.005128	308
273	8114.52127	7833.214924	281
274	8114.52127	7859.424721	255
275	8114.52127	7885.634517	229
276	8114.52127	7911.844313	203
277	8114.52127	7938.05411	176
278	8114.52127	7964.263906	150
279	8114.52127	7990.473702	124
280	8114.52127	8016.683499	98
281	8114.52127	8042.893295	72
282	8114.52127	8069.103091	45
283	8114.52127	8114.52127	0

ɔte:

ɔurce pressure: 24800kPa

ɜceiver's initial pressure: 700kPa

Time, s	End pipe pressure, kPa	Pressure in receiver, kPa	ΔP, kPa
0	101.325	101.325	0
1	8114.52127	3508.598526	4606
2	8114.52127	3534.808322	4580
3	8114.52127	3561.018119	4554
4	8114.52127	3587.227915	4527
5	8114.52127	3613.437711	4501
6	8114.52127	3639.647508	4475
7	8114.52127	3665.857304	4449
8	8114.52127	3692.0671	4422
9	8114.52127	3718.276897	4396
10	8114.52127	3744.486693	4370
11	8114.52127	3770.696489	4344
12	8114.52127	3796.906286	4318
13	8114.52127	3823.116082	4291
14	8114.52127	3849.325879	4265
15	8114.52127	3875.535675	4239
16	8114.52127	3901.745471	4213
17	8114.52127	3927.955268	4187
18	8114.52127	3954.165064	4160
19	8114.52127	3980.37486	4134
20	8114.52127	4006.584657	4108
21	8114.52127	4032.794453	4082
22	8114.52127	4059.004249	4056
23	8114.52127	4085.214046	4029
24	8114.52127	4111.423842	4003
25	8114.52127	4137.633638	3977
26	8114.52127	4163.843435	3951
27	8114.52127	4190.053231	3924
28	8114.52127	4216.263027	3898
29	8114.52127	4242.472824	3872
30	8114.52127	4268.68262	3846
31	8114.52127	4294.892417	3820
32	8114.52127	4321.102213	3793
33	8114.52127	4347.312009	3767
34	8114.52127	4373.521806	3741
35	8114.52127	4399.731602	3715
36	8114.52127	4425.941398	3689
37	8114.52127	4452.151195	3662
38	8114.52127	4478.360991	3636
39	8114.52127	4504.570787	3610
40	8114.52127	4530.780584	3584
41	8114.52127	4556.99038	3558
42	8114.52127	4583.200176	3531
43	8114.52127	4609.409973	3505
44	8114.52127	4635.619769	3479
45	8114.52127	4661.829565	3453
46	8114.52127	4688.039362	3426

47	8114.52127	4714.249158	3400
48	8114.52127	4740.458955	3374
49	8114.52127	4766.668751	3348
50	8114.52127	4792.878547	3322
51	8114.52127	4819.088344	3295
52	8114.52127	4845.29814	3269
53	8114.52127	4871.507936	3243
54	8114.52127	4897.717733	3217
55	8114.52127	4923.927529	3191
56	8114.52127	4950.137325	3164
57	8114.52127	4976.347122	3138
58	8114.52127	5002.556918	3112
59	8114.52127	5028.766714	3086
60	8114.52127	5054.976511	3060
61	8114.52127	5081.186307	3033
62	8114.52127	5107.396103	3007
63	8114.52127	5133.6059	2981
64	8114.52127	5159.815696	2955
65	8114.52127	5186.025493	2928
66	8114.52127	5212.235289	2902
67	8114.52127	5238.445085	2876
68	8114.52127	5264.654882	2850
69	8114.52127	5290.864678	2824
70	8114.52127	5317.074474	2797
71	8114.52127	5343.284271	2771
72	8114.52127	5369.494067	2745
73	8114.52127	5395.703863	2719
74	8114.52127	5421.91366	2693
75	8114.52127	5448.123456	2666
76	8114.52127	5474.333252	2640
77	8114.52127	5500.543049	2614
78	8114.52127	5526.752845	2588
79	8114.52127	5552.962642	2562
80	8114.52127	5579.172438	2535
81	8114.52127	5605.382234	2509
82	8114.52127	5631.592031	2483
83	8114.52127	5657.801827	2457
84	8114.52127	5684.011623	2431
85	8114.52127	5710.22142	2404
86	8114.52127	5736.431216	2378
87	8114.52127	5762.641012	2352
88	8114.52127	5788.850809	2326
89	8114.52127	5815.060605	2299
90	8114.52127	5841.270401	2273
91	8114.52127	5867.480198	2247
92	8114.52127	5893.689994	2221
93	8114.52127	5919.89979	2195
94	8114.52127	5946.109587	2168
95	8114.52127	5972.319383	2142
96	8114.52127	5998.52918	2116
97	8114.52127	6024.738976	2090
98	8114.52127	6050.948772	2064

99	8114.52127	6077.158569	2037
100	8114.52127	6103.368365	2011
101	8114.52127	6129.578161	1985
102	8114.52127	6155.787958	1959
103	8114.52127	6181.997754	1933
104	8114.52127	6208.20755	1906
105	8114.52127	6234.417347	1880
106	8114.52127	6260.627143	1854
107	8114.52127	6286.836939	1828
108	8114.52127	6313.046736	1801
109	8114.52127	6339.256532	1775
110	8114.52127	6365.466328	1749
111	8114.52127	6391.676125	1723
112	8114.52127	6417.885921	1697
113	8114.52127	6444.095718	1670
114	8114.52127	6470.305514	1644
115	8114.52127	6496.51531	1618
116	8114.52127	6522.725107	1592
117	8114.52127	6548.934903	1566
118	8114.52127	6575.144699	1539
119	8114.52127	6601.354496	1513
120	8114.52127	6627.564292	1487
121	8114.52127	6653.774088	1461
122	8114.52127	6679.983885	1435
123	8114.52127	6706.193681	1408
124	8114.52127	6732.403477	1382
125	8114.52127	6758.613274	1356
126	8114.52127	6784.82307	1330
127	8114.52127	6811.032866	1303
128	8114.52127	6837.242663	1277
129	8114.52127	6863.452459	1251
130	8114.52127	6889.662256	1225
131	8114.52127	6915.872052	1199
132	8114.52127	6942.081848	1172
133	8114.52127	6968.291645	1146
134	8114.52127	6994.501441	1120
135	8114.52127	7020.711237	1094
136	8114.52127	7046.921034	1068
137	8114.52127	7073.13083	1041
138	8114.52127	7099.340626	1015
139	8114.52127	7125.550423	989
140	8114.52127	7151.760219	963
141	8114.52127	7177.970015	937
142	8114.52127	7204.179812	910
143	8114.52127	7230.389608	884
144	8114.52127	7256.599404	858
145	8114.52127	7282.809201	832
146	8114.52127	7309.018997	806
147	8114.52127	7335.228794	779
148	8114.52127	7361.43859	753
149	8114.52127	7387.648386	727
150	8114.52127	7413.858183	701

151	8114.52127	7440.067979	674
152	8114.52127	7466.277775	648
153	8114.52127	7492.487572	622
154	8114.52127	7518.697368	596
155	8114.52127	7544.907164	570
156	8114.52127	7571.116961	543
157	8114.52127	7597.326757	517
158	8114.52127	7623.536553	491
159	8114.52127	7649.74635	465
160	8114.52127	7675.956146	439
161	8114.52127	7702.165942	412
162	8114.52127	7728.375739	386
163	8114.52127	7754.585535	360
164	8114.52127	7780.795332	334
165	8114.52127	7807.005128	308
166	8114.52127	7833.214924	281
167	8114.52127	7859.424721	255
168	8114.52127	7885.634517	229
169	8114.52127	7911.844313	203
170	8114.52127	7938.05411	176
171	8114.52127	7964.263906	150
172	8114.52127	7990.473702	124
173	8114.52127	8016.683499	98
174	8114.52127	8042.893295	72
175	8114.52127	8069.103091	45
176	8114.52127	8114.52127	0

ote:
ource pressure: 24800kPa
eceiver's initial pressure: 3500kPa

ime, s	End pipe pressure, kPa	Pressure in receiver, kPa	ΔP, kPa
0	101.325	101.325	0
1	8114.52127	7020.711237	1094
2	8114.52127	7046.921034	1068
3	8114.52127	7073.13083	1041
4	8114.52127	7099.340626	1015
5	8114.52127	7125.550423	989
6	8114.52127	7151.760219	963
7	8114.52127	7177.970015	937
8	8114.52127	7204.179812	910
9	8114.52127	7230.389608	884
10	8114.52127	7256.599404	858
11	8114.52127	7282.809201	832
12	8114.52127	7309.018997	806
13	8114.52127	7335.228794	779
14	8114.52127	7361.43859	753
15	8114.52127	7387.648386	727
16	8114.52127	7413.858183	701
17	8114.52127	7440.067979	674
18	8114.52127	7466.277775	648
19	8114.52127	7492.487572	622
20	8114.52127	7518.697368	596
21	8114.52127	7544.907164	570
22	8114.52127	7571.116961	543
23	8114.52127	7597.326757	517
24	8114.52127	7623.536553	491
25	8114.52127	7649.74635	465
26	8114.52127	7675.956146	439
27	8114.52127	7702.165942	412
28	8114.52127	7728.375739	386
29	8114.52127	7754.585535	360
30	8114.52127	7780.795332	334
31	8114.52127	7807.005128	308
32	8114.52127	7833.214924	281
33	8114.52127	7859.424721	255
34	8114.52127	7885.634517	229
35	8114.52127	7911.844313	203
36	8114.52127	7938.05411	176
37	8114.52127	7964.263906	150
38	8114.52127	7990.473702	124
39	8114.52127	8016.683499	98
40	8114.52127	8042.893295	72
41	8114.52127	8069.103091	45
42	8114.52127	8114.52127	0

te:
urce pressure: 24800kPa
ceiver's initial pressure: 7000kPa

;uperheated Methane*

	Temperature, K							
00	150	200	250	300	350	400	450	500
0228 ;.4 55	0.7661 879.0 10.152	1.0299 984.3 10.757	1.2915 1090.4 11.230	1.5521 1199.8 11.629	1.8122 1314.8 11.983	2.0719 1437.4 12.310	2.3669 1568.8 12.618	2.5911 1708.9 12.914
0228 7.0 53	0.1434 865.0 9.256	0.2006 976.1 9.896	0.2549 1084.7 10.381	0.3083 1195.5 10.785	0.3611 1311.5 11.142	0.4136 1434.7 11.471	0.4657 1566.6 11.781	0.5181 1706.9 12.066
0227 7.8 49	0.0643 843.6 8.797	0.0968 965.5 9.501	0.1254 1077.9 10.002	0.1528 1190.6 10.414	0.1798 1307.9 10.775	0.2063 1432.0 11.106	0.2327 1564.1 11.417	0.2590 1705.3 11.715
0227 .4 42	0.00277 429.8 6.003	0.0446 941.9 9.059	0.0606 1063.6 9.603	0.0751 1180.7 10.030	0.0891 1300.6 10.400	0.1027 1426.5 10.736	0.1162 1560.3 11.050	0.1295 1702.1 11.349
00226 2.5 528	0.00274 430.8 5.973	0.0176 879.3 8.465	0.0281 1032.9 9.155	0.0363 1160.5 9.621	0.0438 1286.0 10.008	0.0510 1415.7 10.354	0.0579 1552.1 10.674	0.0648 1696.0 10.978
00226 5.7 515	0.00271 432.2 5.946	0.00615 734.0 7.623	0.0173 999.8 8.847	0.0234 1140.0 9.359	0.0287 1271.7 9.765	0.0338 1405.1 10.121	0.0386 1544.2 10.440	0.0432 1690.0 10.756
00225 8.9 502	0.00268 433.8 5.920	0.00411 660.5 7.209	0.0119 964.4 8.590	0.0171 1119.7 9.158	0.0213 1257.7 9.584	0.0252 1394.9 9.951	0.0289 1536.6 10.283	0.0324 1684.4 10.595
00224 52.1 489	0.00266 435.5 5.897	0.00375 644.5 7.090	0.00888 928.5 8.364	0.0133 1099.6 8.991	0.0169 1244.2 9.437	0.0201 1385.2 9.814	0.0231 1529.4 10.153	0.0260 1679.0 10.469
00223 70.2 458	0.00261 440.7 5.843	0.00337 630.2 6.930	0.00555 860.0 7.953	0.00852 1054.1 8.664	0.0111 1213.1 9.155	0.0134 1362.8 9.555	0.0155 1513.0 9.907	0.0175 1667.0 10.233
00221 78.3 429	0.00256 446.5 5.796	0.00318 626.5 6.829	0.00447 825.0 7.719	0.00644 1019.8 8.426	0.00837 1187.2 8.944	0.0101 1343.8 9.362	0.0118 1498.9 9.727	0.0133 1656.9 10.060
.00218 94.7 .373	0.00249 459.6 5.714	0.00296 629.2 6.690	0.00369 804.4 7.471	0.00474 982.9 8.122	0.00593 1153.6 8.649	0.00708 1316.8 9.085	0.00818 1478.5 9.465	0.00924 1642.2 9.811
	0.00244 473.8 5.645	0.00282 637.7 6.588	0.00336 802.4 7.323	0.00406 970.1 7.935	0.00486 1137.8 8.451	0.00569 1303.0 8.893	0.00560 1467.7 9.280	0.00729 1634.7 9.633
	0.00239 488.8 5.584	0.00272 648.9 6.507	0.00315 807.7 7.215	0.00368 969.0 7.802	0.00428 1132.8 8.307	0.00492 1297.8 8.748	0.00555 1464.2 9.139	0.00616 1633.2 9.496

ıd rounded off from the tables of Goodwin, NBS Tech. Note 654, 1974. v = specific volume, m^3/kg; h = specific enthalpy, kJ/kg; s = specific entropy,

lynamic diagram from 0.1 to 400 bar and 620°C, see the 1993 ASHRAE *Handbook—Fundamentals* (SI ed.).
l superheat tables and a chart to 6000 psia, 680°F appear in Stewart, R. B., R. T. Jacobsen, et al., *Thermodynamic Properties of Refrigerants*, ASHRAE, 36 (521 pp.). For specific heat, thermal conductivity, and viscosity, see *Thermophysical Properties of Refrigerants*, ASHRAE, 1993. See also Friend et al., *J. Phys. Chem. Ref. Data*. **18**, 2 (1989): 583–638.